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NWL Report No. 1858

A TEST SET FOR DETERMINING THE COOK-OFF TEMPERATURES OF POWER CARTRIDGES

by
J. Miller, Jr.
and
S. T. Fox

Warhead and Terminal Ballistics Laboratory

U. S. NAVAL WEAPONS LABORATORY
DAHLGREN, VIRGINIA

U. S. Naval Weapons Laboratory
Dahlgren, Virginia

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CONTENTS

ABSTRACT

A power cartridge cook-off test set is described, tests conducted to check out the test set are summarized, and a procedure for obtaining power cartridge cook-off data is outlined.

FOREWORD

This is the final report on the design, construction and testing of a power cartridge cook-off test set and on the development of a procedure for obtaining cook-off data on power cartridges from this test set. This work was conducted under Problem Assignment No. 1 of WEPTASK NO. RMMO-33-020/210-1/F008-11-001. The cook-off test set was designed and constructed by the Armour Research Foundation of Illinois Institute of Technology under NWL Contract No. N178-7643 during September 1959 to May 1960. The test set was received and installed at the Naval Weapons Laboratory during May 1960 to September 1961. Tests leading to the acceptance of the test set and the development of a procedure for obtaining cook-off data on power cartridges from this device were performed during September 1961 to May 1962.

This report was reviewed by the following personnel of the Warhead and Terminal Ballistics Laboratory:

S. E. HEDDEN, Head, Research Branch, Cartridge Actuated Devices Division
J. J. GLANCY, Head, Cartridge Actuated Devices Division
R. I. ROSSBACHER, Director

APPROVED FOR RELEASE:

/s/ R. H. LYDDANE
Technical Director

INTRODUCTION

The cook-off test set was designed and built as a device for determining the temperatures and times at which complete power cartridges "cook off" when exposed to temperature-time environments simulating in so far as practical those encountered by cartridges installed in devices under service conditions. The answers to two interrelated questions were sought: (1) at what temperature will a cartridge cook off when subjected to a temperature environment in which the temperature is increased at given fixed rates of rise; and (2) at what time will a cartridge cook off when subjected to a temperature environment in which the temperature is held constant at a given level.

The term "cook-off" as applied in this report to power cartridges is used with the following connotations:

Cook-off is to denote the initiation and deflagration or explosion of one or more explosive components of the cartridge as a direct result of the complete cartridge having been exposed to a given temperature-time environment. In general, the energy output derived from the cartridge would be expected to approximate that obtained when the cartridge is ignited in its normal manner. However, depending upon the inherent characteristics of the explosives used, this cook-off energy output may be modified as a result of the exposure of the explosives to the temperature-time environment. A simple venting of a cartridge, such as that resulting from a pressure build-up generated by heating of entrapped air and other gases within the cartridge, but not accompanied by any appreciable chemical energy release from the explosive components, is not considered a true cook-off.

The cook-off test set was not designed as an instrument for determining either the autoignition temperatures of discrete explosive materials or the spontaneous combustion temperatures of other combustible materials contained in the cartridge, although it could be used to generate these data.

The term "cook-off temperature" is restricted herein to designate the temperature of the environment of the cartridges at time of cook-off without regard for temperatures existing within the cartridge at this time. In the cook-off test set, the cook-off temperature is that of the oil bath at time of cartridge cook-off.

Similarly, the term "cook-off time" is restricted to mean the time from initial exposure of a cartridge to a given temperature-time environment to cartridge cook-off.

Rather than attempt to directly simulate temperature-time environment which might be encountered by power cartridges installed in devices in service conditions, an approach considered impractical in view of the wide variety of cartridges, devices and environments which would have to be considered, the following approach was followed: The cook-off test set was so designed that the temperature-time environment encountered by cartridges in the device could be expected to exceed in severity by a reasonable margin in most cases at least, those encountered in actual service applications. To be more specific, the rate of heat transfer to the cartridge when installed in the cook-off test set would equal or exceed that to be expected to exist in actual devices in service conditions. By this approach, it would be expected that the data generated in the cook-off test set would provide upper limits, and hence some margin of safety, in extrapolating from the test set to service applications. By this approach, it could be expected that if a cartridge cooked off at an environmental temperature of 425°F when the rate of rise in temperature is 10°F/min in the cook-off test set, then in a service condition entailing an equal rate of rise in temperature, cook-off would not be expected to occur at an environmental temperature less than 425°F and probably at a somewhat higher temperature. Similarly, a cartridge exposed to a constant temperature environment in the cook-off test set could be expected to cook-off in a somewhat shorter time than it would in a service condition at the same environmental temperature.

In the cook-off test set, the rate of heat transfer to the cartridge was maximized by using materials having high thermal conductivity for cartridge chambers, by sand blasting and black anodizing the outside surfaces of these chambers, and by using a circulated oil bath as the temperature environment. Cartridge chambers in the test set can conform dimensionally as closely as required to cartridge chambers in service devices.

To check out the operation of the test set and to develop a general procedure for the acquisition of cartridge cook-off data a series of tests were conducted with MARK 13-0 separation cartridges.

DESCRIPTION OF THE TEST CARTRIDGES

The MARK 13 MOD 0 separation cartridges contain the MARK 11 electric ignition element and a main charge of 0.42 gram of a single base propellant (SPDN 8880 or 7807). Each cartridge was instrumented with two iron-constantan thermocouples as shown in Figure 1. One thermocouple junction was held in contact with the outer shell of the ignition element by the ignition retaining bushing. A second thermocouple junction was located in the propellant bed at the approximate center of the main charge cavity of the cartridge.

DESCRIPTION OF THE COOK-OFF TEST SET

The cook-off test set is divided into two major subassemblies: (1) the test tank assembly shown in Figures 2 through 5, and (2) the temperature control system shown in Figure 6. These figures show the equipment installed at the Naval Weapons Laboratory.

The test tank assembly consists of a 13.5 gallon stainless steel insulated tank containing General Electric 81644 silicone fluid, the heating elements, the agitator, and the tank cover. The heating elements consist of 25, 1-kw, tubular, quartz infrared lamps vertically mounted and equally spaced radially between two concentric copper contact rings. Each ring is connected to the power source and properly insulated from the tank.

A 7-inch diameter, 7-bladed aluminum agitator is centrally located in the base of the tank. The agitator shaft extends through a sealed bearing capsule mounted in the tank and is driven by a 1/8 hp motor. The motor speed can be varied by a variable voltage transformer.

The tank cover provides an insulated cover for the tank and contains the five cartridge chambers and the vent and collar assembly. The tank cover, chambers and vent assembly are raised and lowered by means of two cushioned air cylinders. These air cylinders are mounted vertically to the base plate.

Pneumatic actuation of the raising and lowering of the tank cover assembly can be accomplished either through the switch in the panel box on the base plate or remotely by means of a switch located outside the test cell. The needle valves on the 3-way, solenoid-actuated valve mounted on the base plate may be adjusted

to vary the raising and lowering speed. The tank cover may be retained in the top position, as shown in Figure 2, by inserting dowel pins through holes in the legs and under the tank cover guide shafts.

Sets of five aluminum chambers and caps are manufactured for each type of cartridge to be tested. One set of chambers is made to serve for testing families of cartridges varying only in total length by making the chambers long enough to accommodate the longest cartridge of the family. The outside diameters of the chambers are sand blasted and black anodized to increase the transfer of heat from the silicone bath through the chamber walls to the cartridge.

The components required for the complete automatic time-temperature control system are indicated on the block diagram of Figure 7 (based on Figure 4 of reference (a)). This system was supplied by the Barber-Coleman Company. The following description of the operation of this system is excerpted from reference (a).

The Wheelco Chronotrol provides a complete automatic program control to enforce a predetermined time-temperature cycle on the heating equipment. After initiation, the program is maintained without the need of further adjustment or supervision throughout the complete operating cycle.

The simple program mechanism of the Chronotrol continuously positions the control point of a "Resistance Thermotrol" so that a heating cycle with holding periods at one or more levels may be relayed into control action via a quick-acting linkage. The temperature sensor, indicated in Figure 7, is the element which produces the electrical impulse used as the Chronotrol sensing unit. The program mechanism consists of a synchronous motor that rotates at a constant but selected speed. The control setting index of the instrument is mechanically coupled to a lever arm that rides on the contour of a disc cam mounted on the motor shaft. The shape of this programmed disc corresponds to the desired cycle, so the combination of time and control levels is coordinated to automatically maintain a complete program. The magnetic modulated current (MMC), output type, three function controller is used with the Chronotrol for this application. The magnetic modulator converts a d.c. error signal to a.c. and also adds reset and rate corrections to the error signal. This signal is relayed through the final control device, the pilot amplifier, to the saturable core reactor.

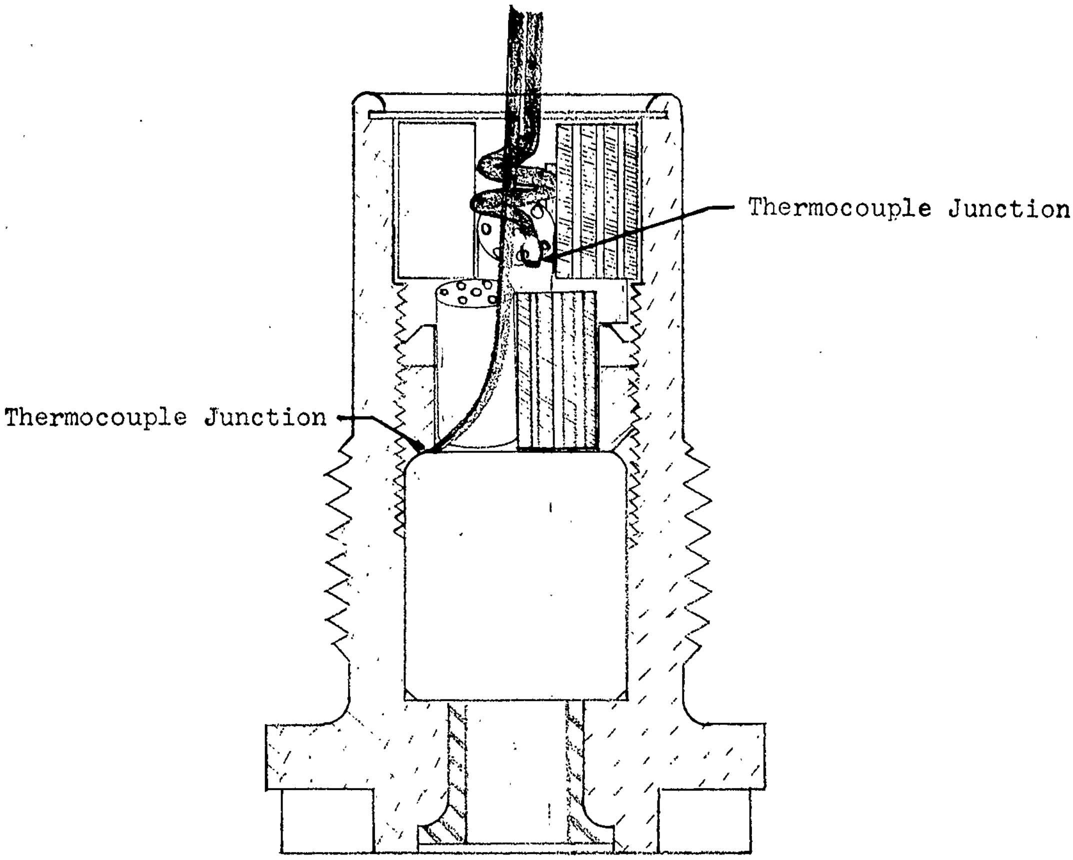
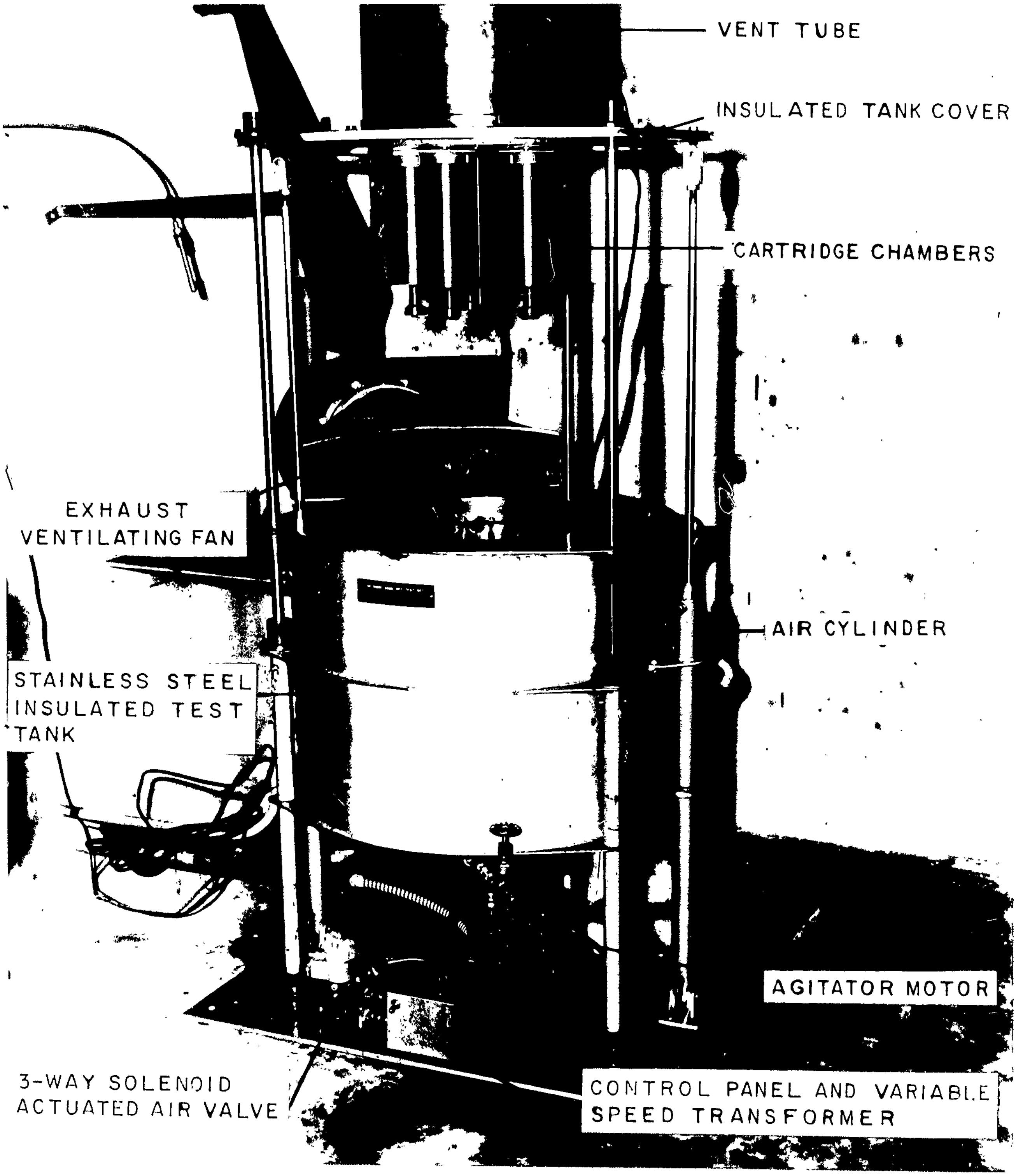


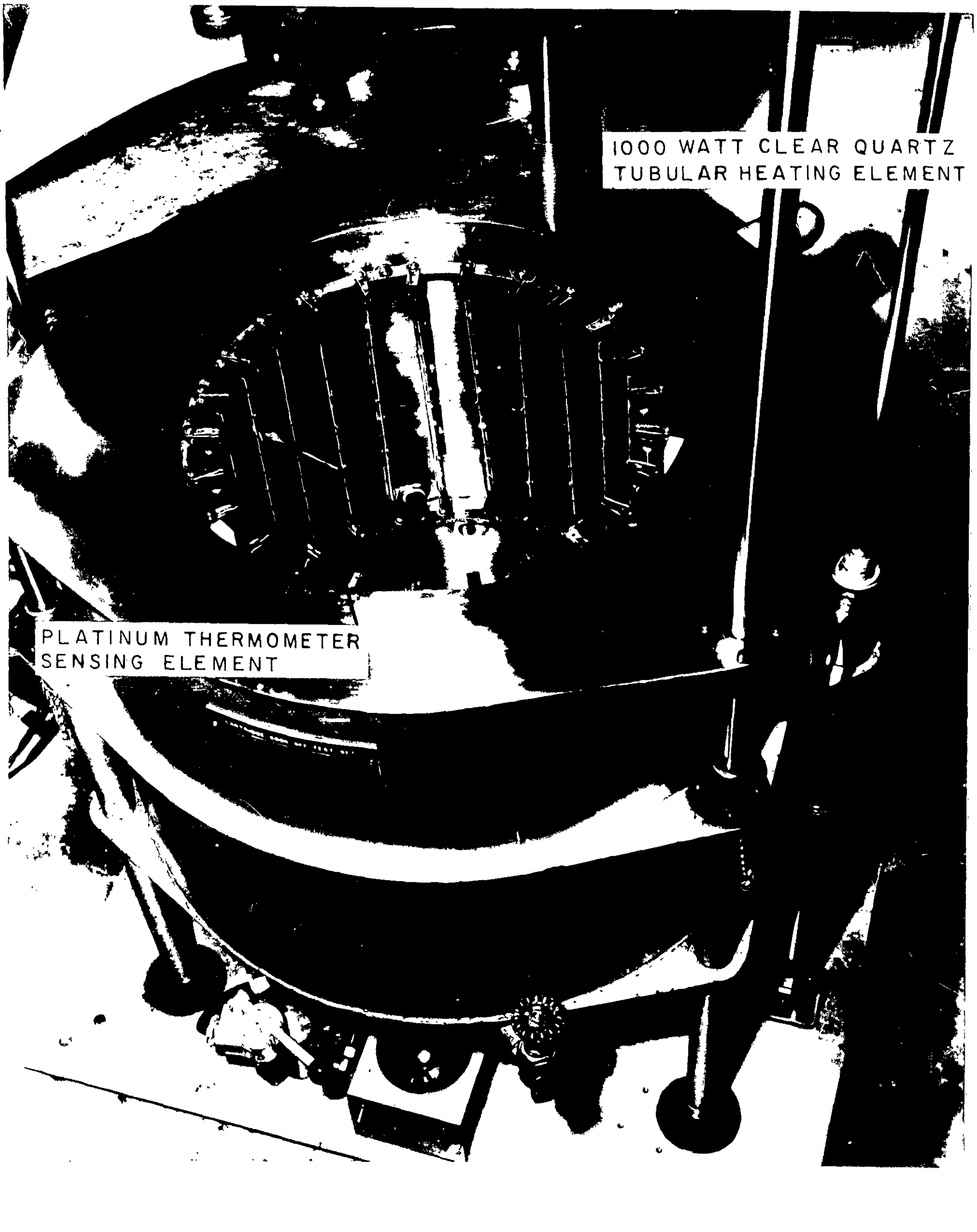
Figure 1

Separation Cartridge MARK 13 MOD 0 With Thermocouples Installed



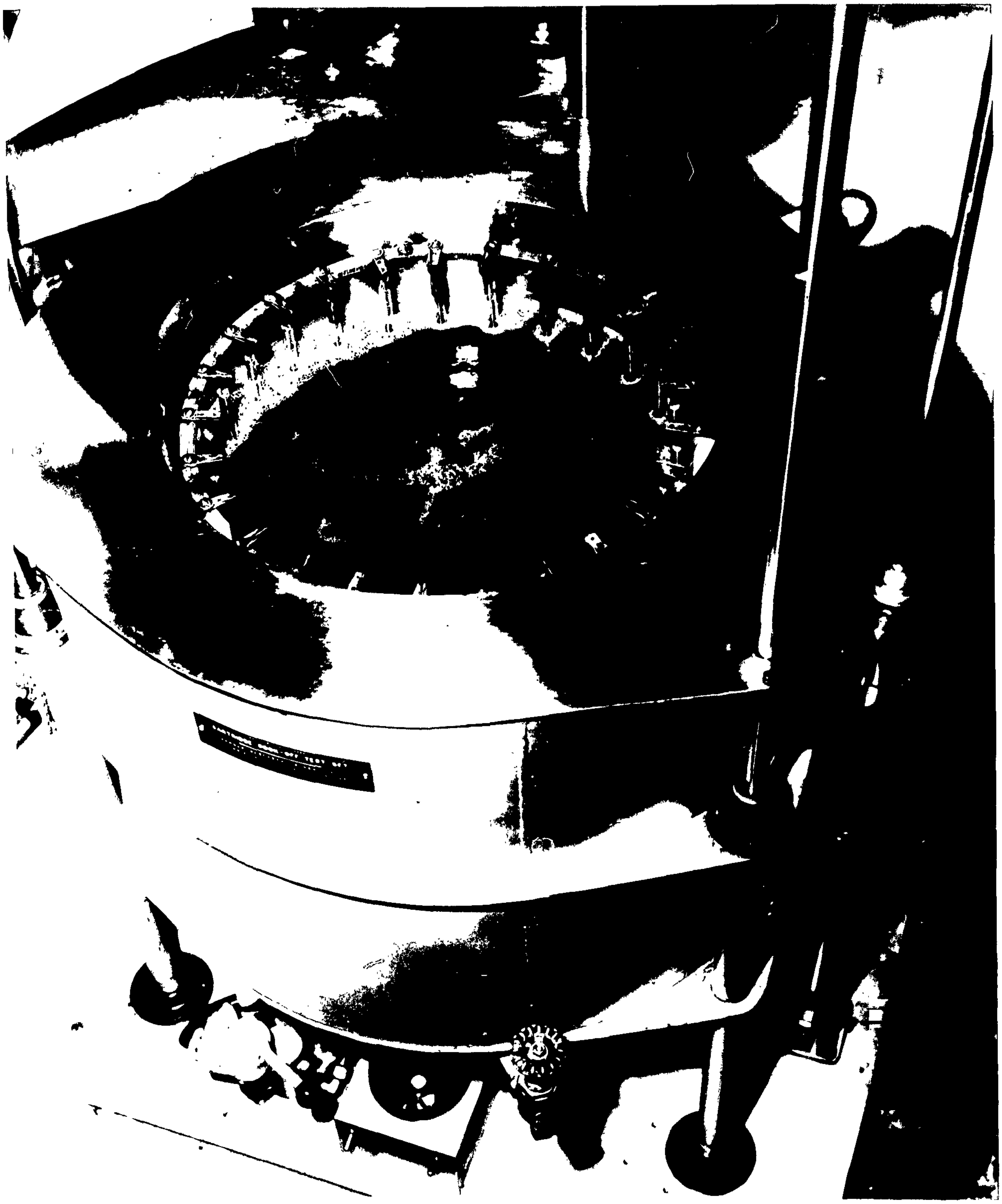
PHD-90041-12-62 Figure 2 7 December 1962

Test Tank Assembly - Cover in Raised Position



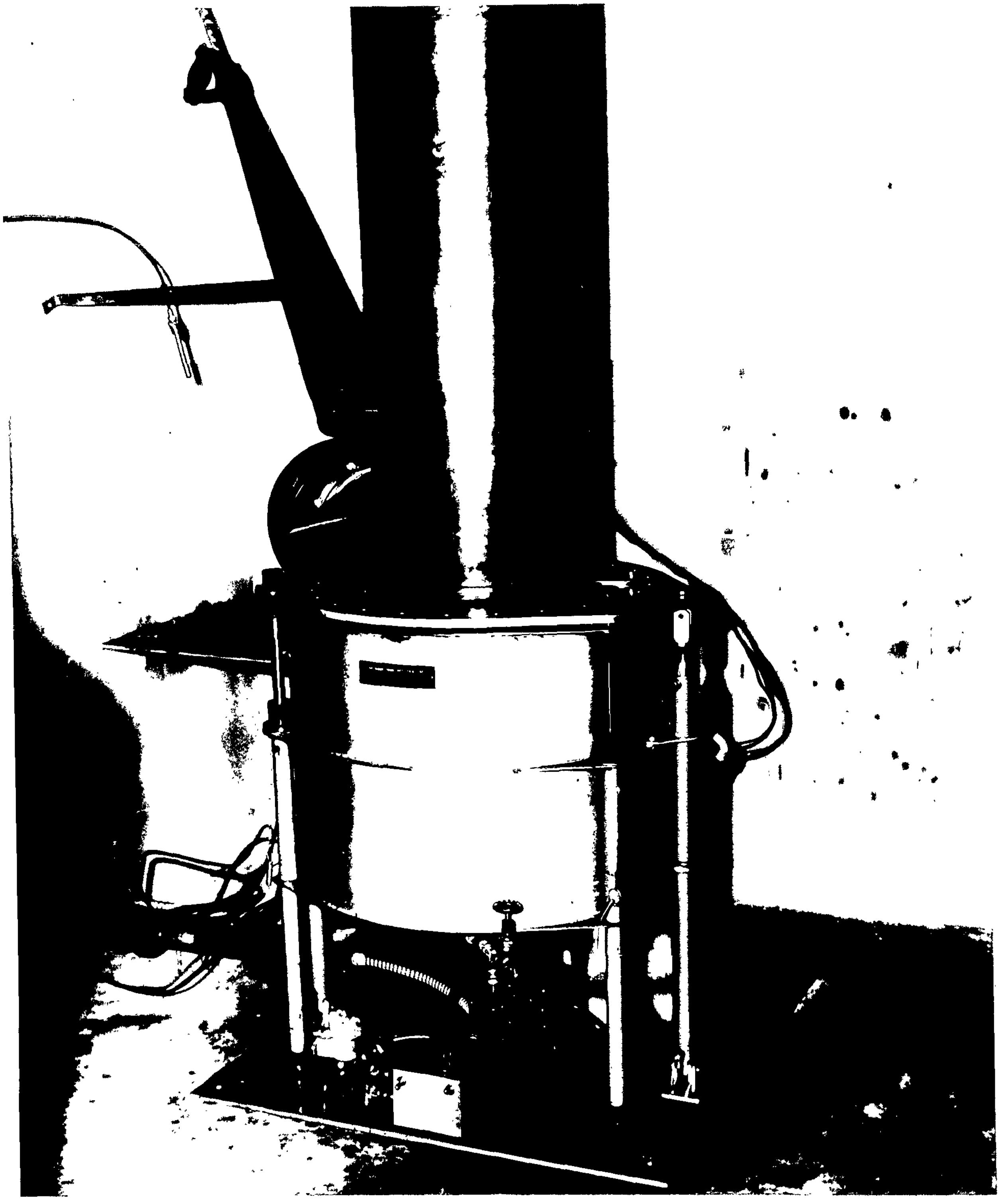
PHD-90044-12-62 Figure 3 7 December 1962

Interior View - Test Tank Assembly



PHD-90043-12-62 Figure 4 7 December 1962

Test Tank Assembly with Silicone Fluid



PHD-90040-12-62 Figure 5 7 December 1962

Test Tank Assembly - Cover in Lower Position

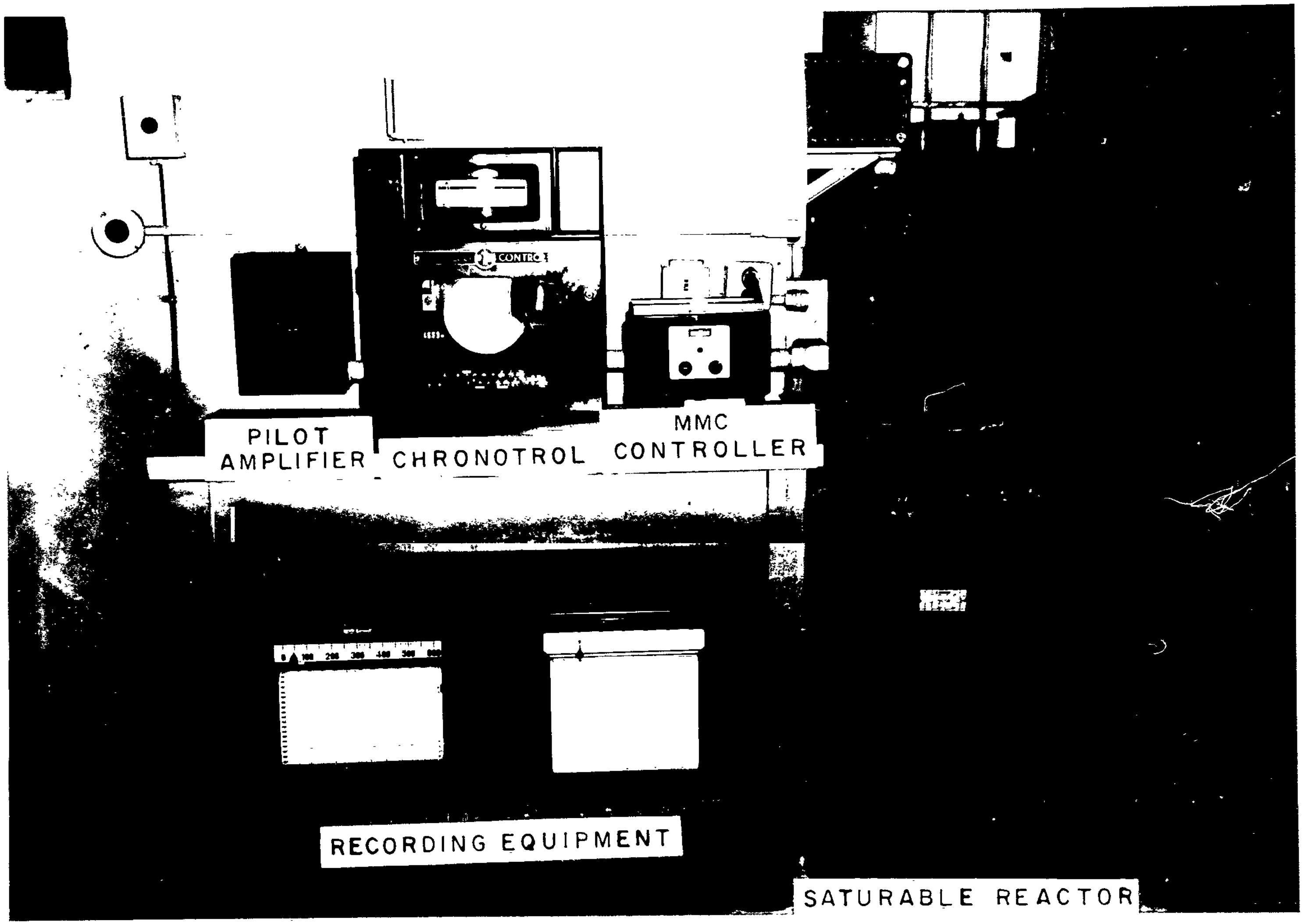


Figure 6

Temperature Controlling and Recording Equipment

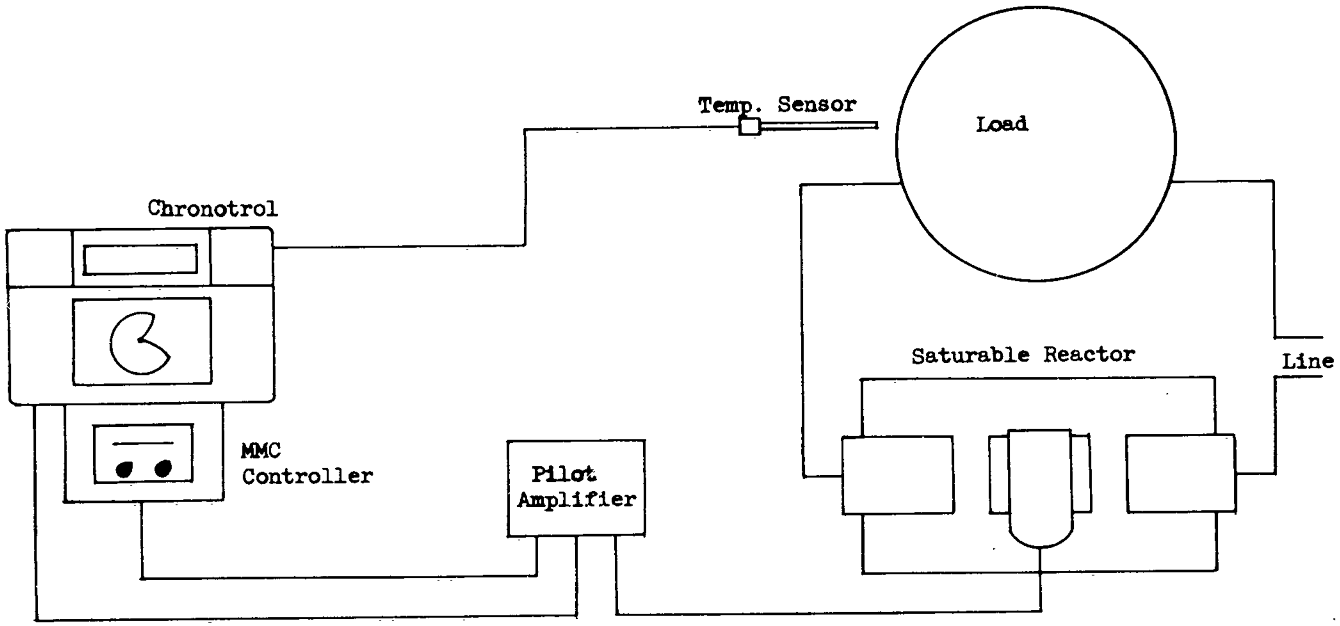


Figure 7

Block Diagram of Temperature Control System

The 22-kva saturable core reactor controls the power input to the 25, 1-kw, tubular, quartz infrared lamps mounted in the cook-off test tank. These reactors are devices similar to ordinary a.c. transformers, the essential difference being that they have extra d.c. windings called control windings. The control windings of a saturable core reactor regulate the degree of saturation of the core and thus the impedance of the a.c. winding. When the d.c. signal current is varied in a manner proportional to the deviation controlled variable with respect to the control set point, it is possible to use the saturable core reactor as variable impedance to control power input. The output of the saturable reactor can be varied through an infinite number of power levels from a maximum of 90% of rated capacity to a minimum of 3% as demands of the sensing unit vary from a maximum to a minimum.

The sensitivity of the control equipment is rated as a constant ±0.5°F/min band over the complete temperature-time cycle to 500°F.

The recording equipment used with the cook-off test set is a 24-channel strip chart potentiometer (Minneapolis Honeywell Model Electronic 15).

For detailed instructions for operating the test set in both the dynamic and static modes, reference should be made to reference (a) and to Naval Weapons Laboratory instructions on operation and safety procedures for the test set.

TEST PROCEDURE, RESULTS AND DISCUSSION

The following tests were performed in the power cartridge cook-off test set to check out the equipment and to establish a procedure for obtaining cook-off data on power cartridges.

a. As a precautionary measure and to check the accuracy of the available cams along with the capabilities of the test equipment, three trial runs were conducted with the 5, 10 and 20°F/min cams in which oil bath temperatures were recorded. See Figures 8 through 10 for results. Previous to these tests, difficulties were encountered with the stirrer bearing capsule assembly during high temperature operations. The stirrer shaft seized the bearing capsule interface. However, this problem was corrected by inserting a graphite bearing.

b. Four instrumented cartridges were simultaneously subjected to a temperature increasing from ambient at the rate of approximately 5°F/min. See Figures 11 through 14 for results.

c. Four instrumented cartridges were simultaneously subjected to a temperature increasing from ambient at the rate of approximately 10°F/min. See Figures 15 through 18 for results.

d. Three instrumented cartridges were simultaneously subjected to a temperature increasing from ambient at the rate of approximately 20°F/min. See Figures 19 through 21 for results.

e. The oil bath temperature was raised and held at 300°F and two instrumented cartridges immersed in the oil bath by remote control after the 300°F temperature was established. See Figures 22 and 23 for results.

f. The oil bath temperature was raised and held at 325°F and two instrumented cartridges immersed in the oil bath by remote control after establishing the 325°F temperature. See Figure 24 for results.

g. The oil bath temperature was raised and held at 350°F and two instrumented cartridges immersed in the oil bath by remote control after the 350°F temperature was established. See Figure 25 for results.

As indicated above, the results of individual tests are presented in Figures 8 through 25. Figure 26 is a composite graph summarizing the results from tests (b) through (g).

a. The average rates of rise of the oil bath temperature, as determined by straight lines visually fitted to the data obtained from the three trial runs, were as follows:

5°F/min cam	-	5.1°F/min
10°F/min cam	-	9.2°F/min
20°F/min cam	-	19.9°F/min

Maximum deviations from the visually fitted lines were approximately as follows:

5°F/min cam	-	3°
10°F/min cam	-	3°
20°F/min cam	-	4°

These deviations from linearity in temperature rises are insignificant in their effects on the data obtained on cook-off temperatures.

The above two sets of data may be taken as an approximate measure of the accuracy with which the present cams were cut superimposed on the capability of the control equipment to maintain a constant rate of temperature rise.

b. The temperature-time curves presented in Figures 11 through 26 were produced from data recorded from a thermocouple in the oil bath and from the two thermocouples in the cartridges located as shown in Figure 1. Temperatures were recorded at approximately 14 second intervals from these thermocouples by means of an automatic multichannel temperature recorder. The two cartridge thermocouples, while not required for determining the cook-off temperatures and times of cartridges as defined in the Introduction, provided an indication of the temperature lags in the cartridges compared to that of the oil bath. Also, the thermocouple within the propellant bed provided a convenient means of recording the times of cook-off on the temperature-time recordings, though this could be done by other means. The cartridge thermocouples, particularly that in the propellant bed, provide information on the initiation of exothermic reaction within the main charge and of the transition of these into deflagrations. However, it is considered that these data as recorded on these tests is too gross to permit a precise determination of autoignition temperature of specific explosive components contained in the cartridges.

c. In the 300°F constant temperature test, the oil bath temperature was increased at 20°F/min after 58 minutes. This induced cook-off in about 3 minutes at an oil bath temperature of about 360°F, which is comparable to the oil bath temperature at cook-off on the 20°F/min test.

On the basis of the tests conducted, the following cook-off data are established for the MARK 13 cartridge as tested.

<u>Dynamic Cook-Off Temperatures:</u>

At 5°F/min	330°F
At 10°F/min	343°F
At 20°F/min	362°F

<u>Static Cook-Off Time:</u>

At 300°F	> 60 min
At 325°F	7 min
At 350°F	3 min

CONCLUSIONS

On the basis of the tests reported herein, it is concluded that the power cartridge cook-off test set has the following capabilities:

a. General capabilities - To determine and record (1) the temperature at which power cartridges cook off when subjected to linear rates of temperature increase, and (2) the times required to cook off power cartridges when subjected to various fixed environmental temperatures.

b. Specific capabilities - (1) Cartridges varying in size from 0.25 inch diameter by 0.5 inch long to 3 inches diameter by 6 inches long containing charges equivalent to 150 grams of nitrocellulose propellant can be tested. (2) The temperature of the cartridge environment can be increased at essentially linear rates of temperature increase ranging between 5°F/min and 20°F/min. Temperatures will not deviate from these linear rates of rise by more than about 3 to 4°F at any time of the heating cycle. (3) The temperature of the cartridge environment can be maintained at fixed temperatures up to a maximum of 500°F for periods up to 6 hours. Fixed temperatures are held to within approximately ±2°F. (4) Cartridges can be inserted into and removed from the temperature environment by remote control to reduce the hazards to which the operator might be subjected.

However, the capabilities of the equipment could be improved with the installation of a heat exchanger to cool the oil after each test run. This would increase the number of tests that could be conducted daily.

On the basis of this series of tests on the MARK 13 cartridge, the following procedures appear reasonable for obtaining cook-off data on power cartridges generally. These procedures may be modified later on the basis of accumulated experience.

a. Instrument all test cartridges with at least one thermocouple located in the geometric center of the main propellant charge.

b. Perform a dynamic cook-off test at the 5, 10 and 20°F/min rate using five instrumented cartridges for each test. Record temperatures from the thermocouple in the oil bath and from the thermocouples in the cartridges until after cook-off has occurred or until all reaction within the cartridge has ceased.

c. Perform a static cook-off test at a temperature approximately 25°F below the indicated cook-off temperature of the 5°F/min dynamic test. Record temperatures from the thermocouples in the oil bath and cartridges and time to cook-off. Continue test to cook-off or to one hour whichever transpires first. Perform additional static tests at 25°F increments above and below that of the first test until the following temperature limits are established: (1) static temperature which will induce cook-off within 5 minutes and, (2) static temperature which the cartridges will sustain for one hour without cook-off.

d. Tabulation of the results may be in the following form:

CARTRIDGE COOK-OFF DATA

Cartridge ______ (official designation) ______

Dynamic Cook-Off Temperatures:

At 5°F/min	______°F
At 10°F/min	______°F
At 20°F/min	______°F

Static Cook-Off Times:

At ______°F	______Min.
At ______°F	______Min.
At ______°F	______Min.

REFERENCE

(a) Armour Research Foundation of Illinois Institute of Technology Final Report ARF 8183-7 of May 1960

APPENDIX A

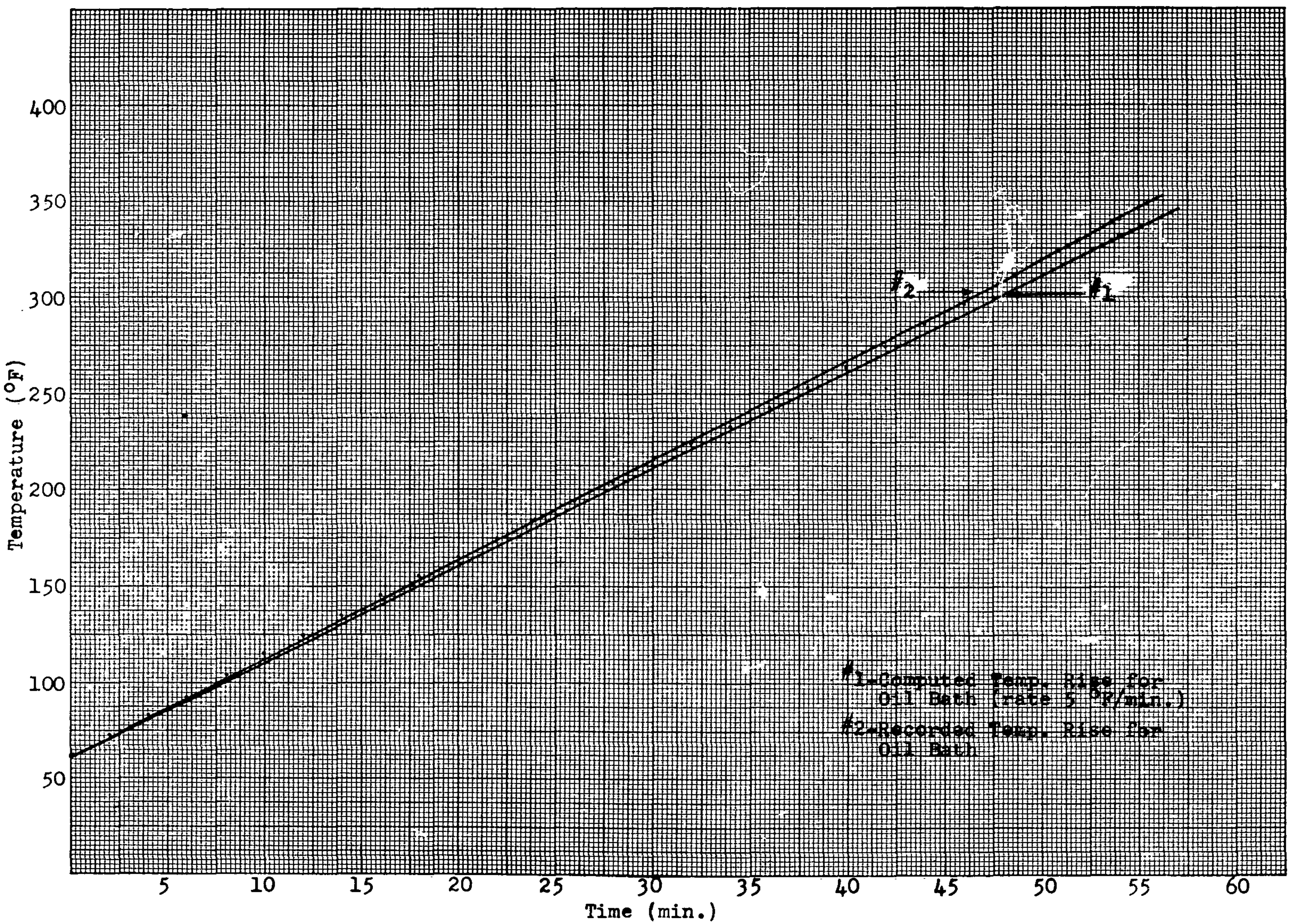


Figure 8

Computed vs Recorded Temperature-Time Curve for 5°F/min Rate-of-Rise Cam

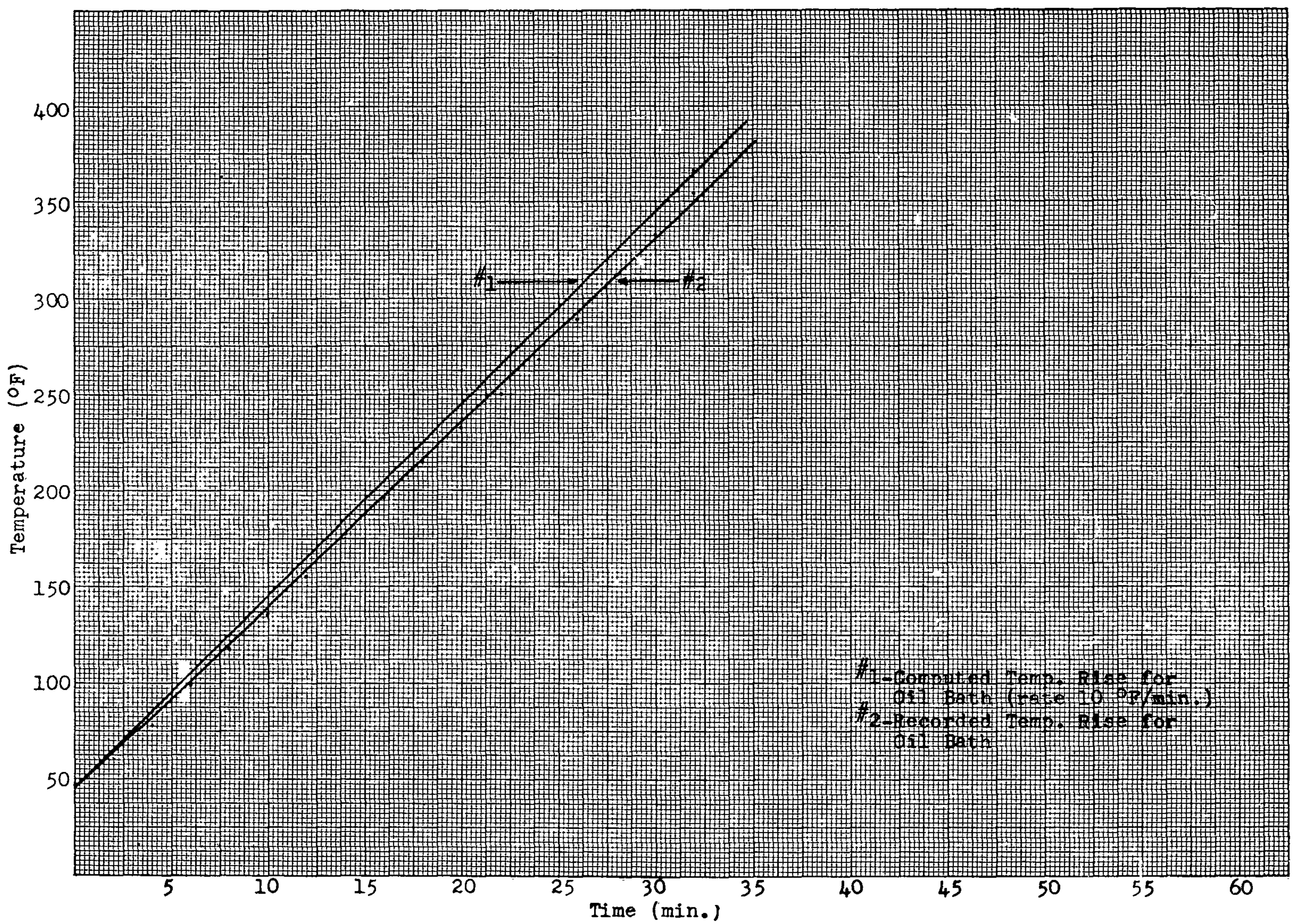


Figure 9

Computed vs Recorded Temperature-Time Curve for 10°F/min Rate-of-Rise Cam

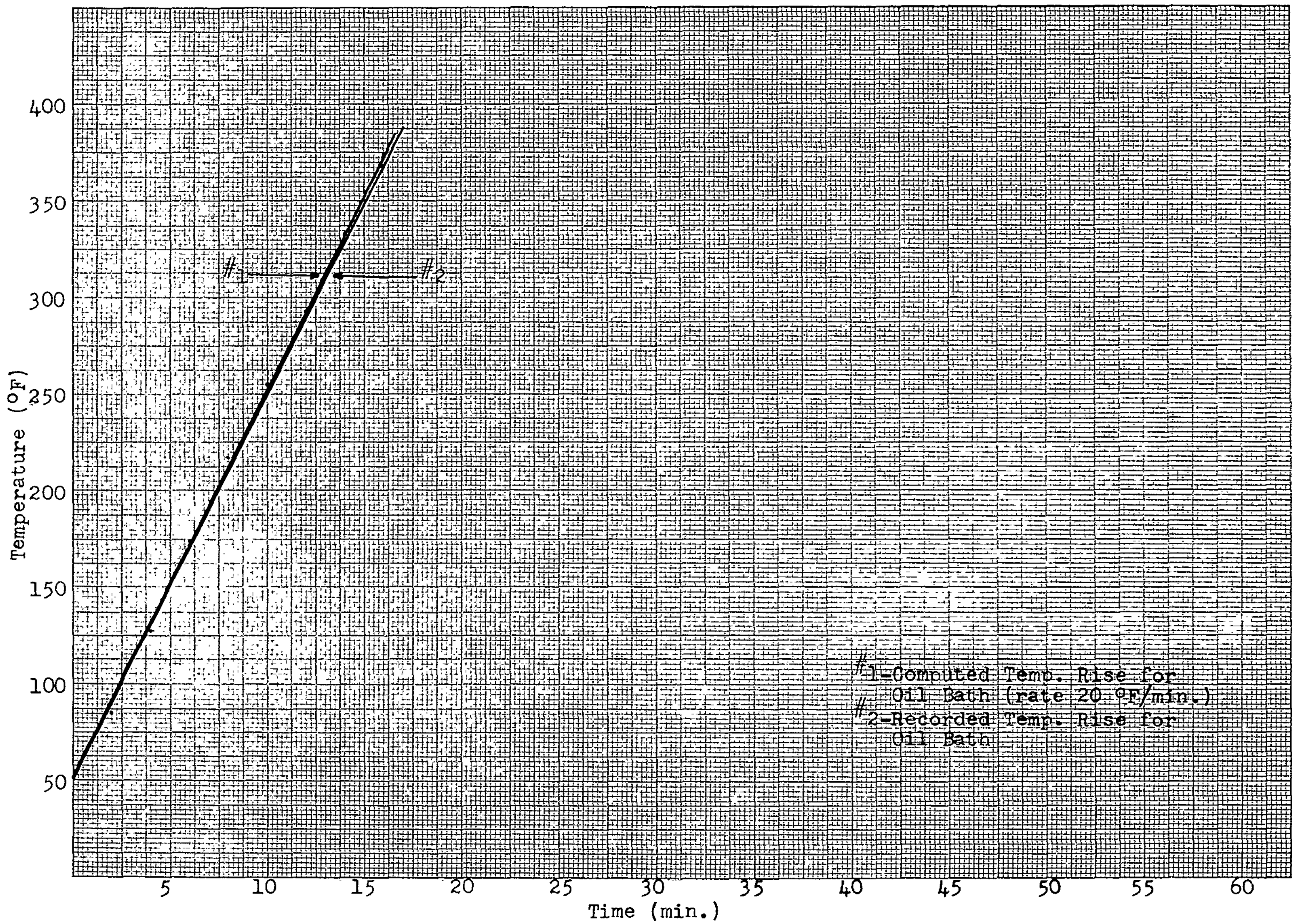


Figure 10

Computed vs Recorded Temperature-Time Curve for 20°F/min Rate-of-Rise Cam

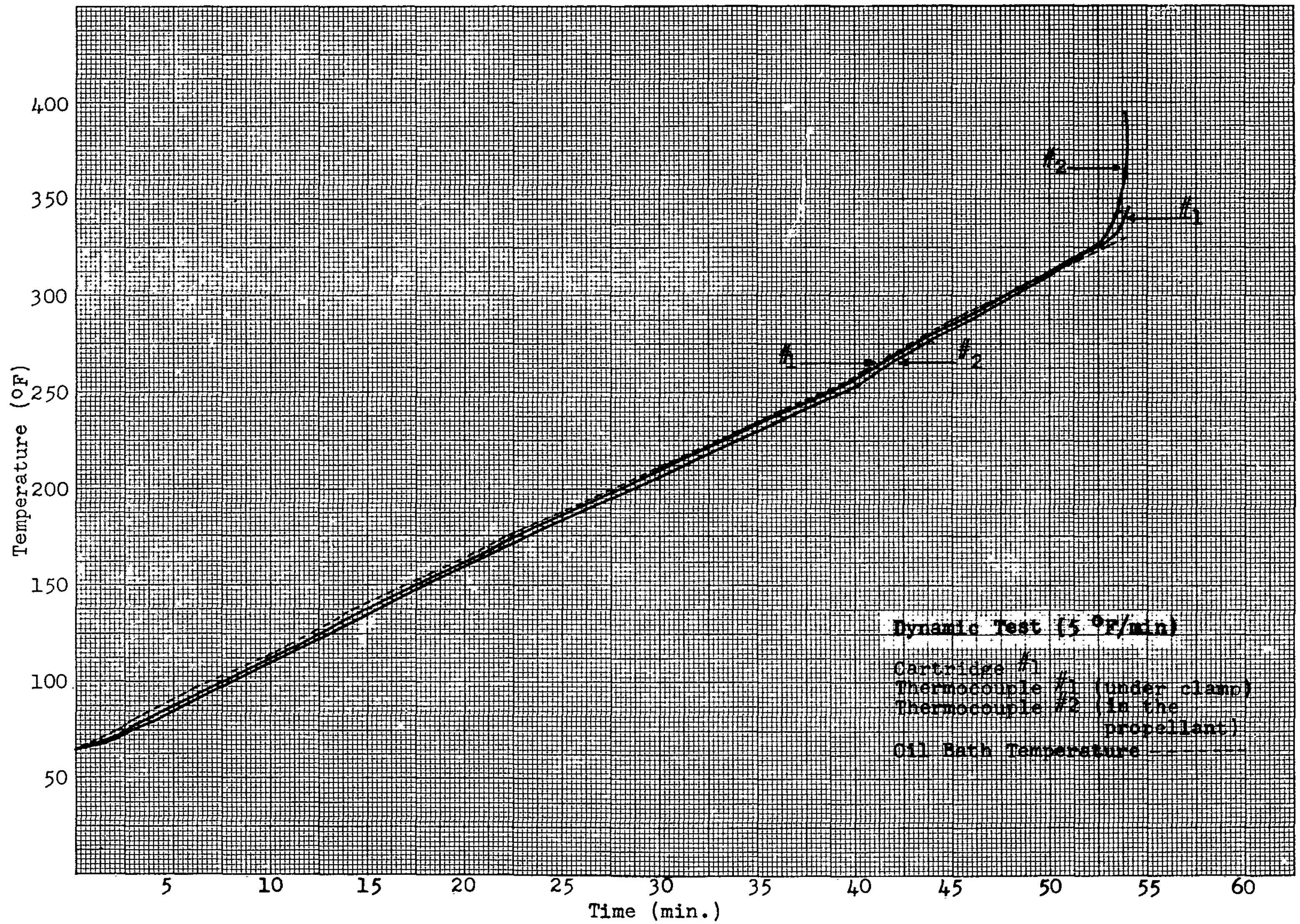


Figure 11

Temperature-Time Curve Controlled By 5°F/min Rate-of-Rise Cam

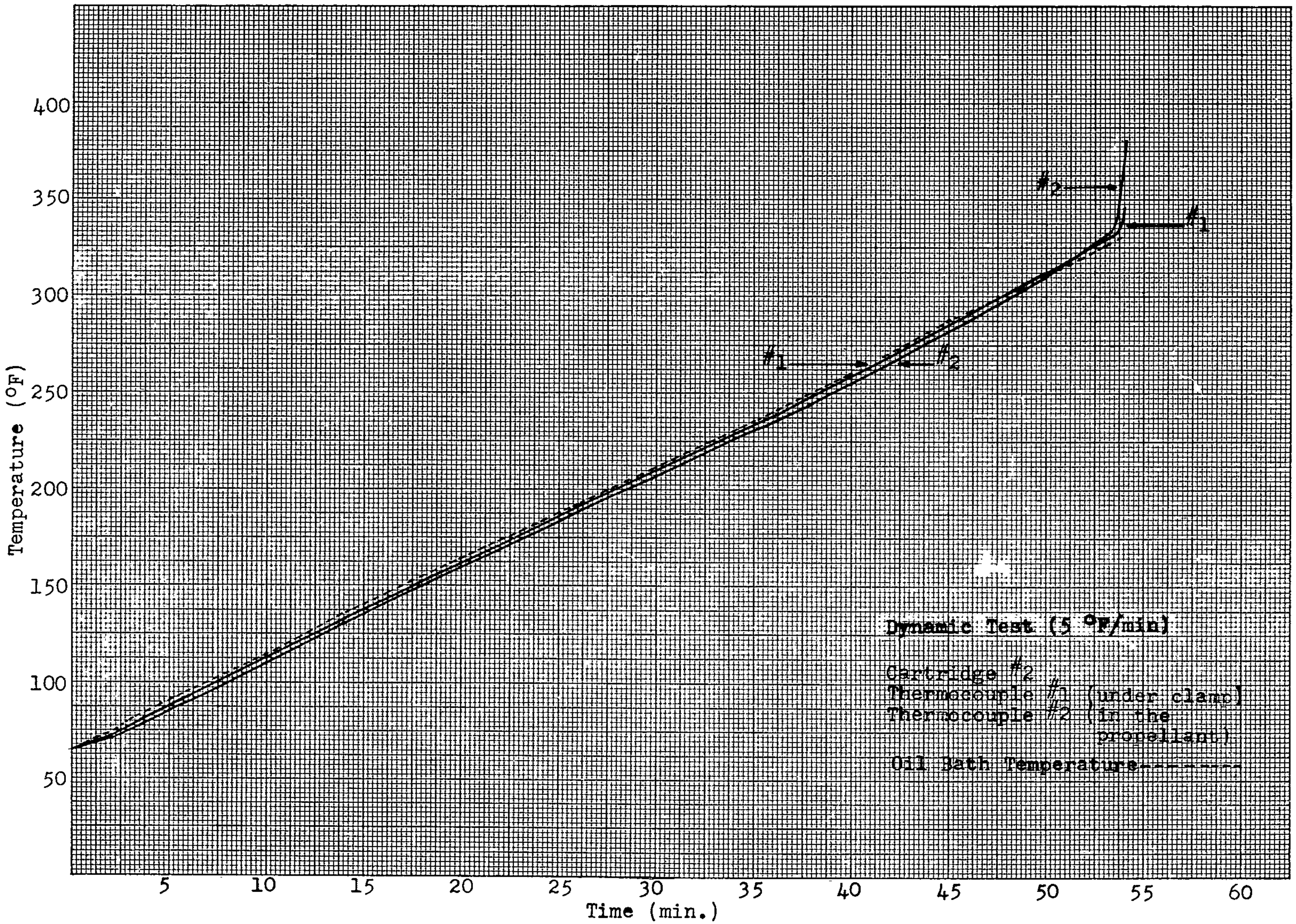


Figure 12

Temperature-Time Curve Controlled By 5°F/min Rate-of-Rise Cam

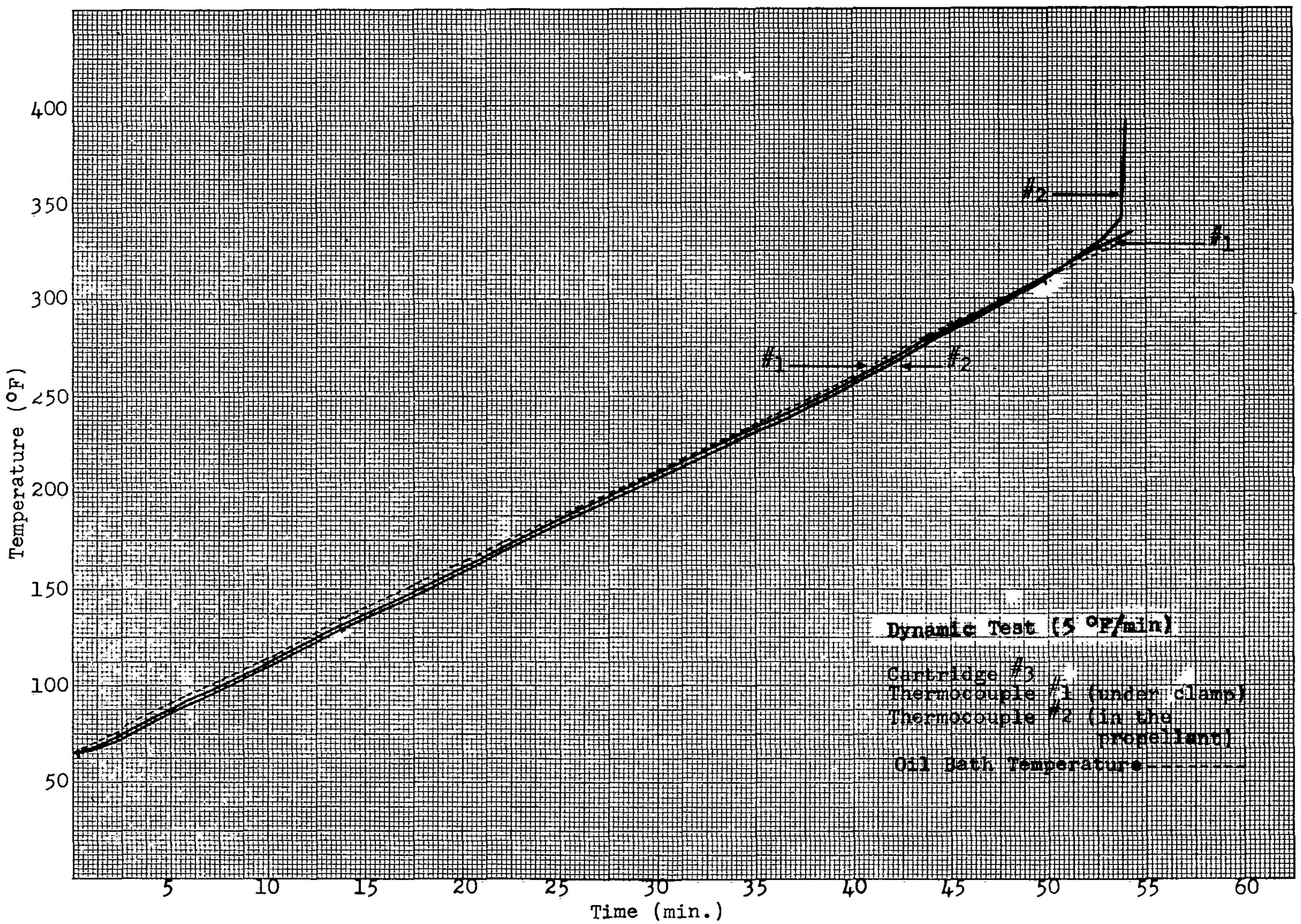


Figure 13

Temperature-Time Curve Controlled By 5°F/min Rate-of-Rise Cam

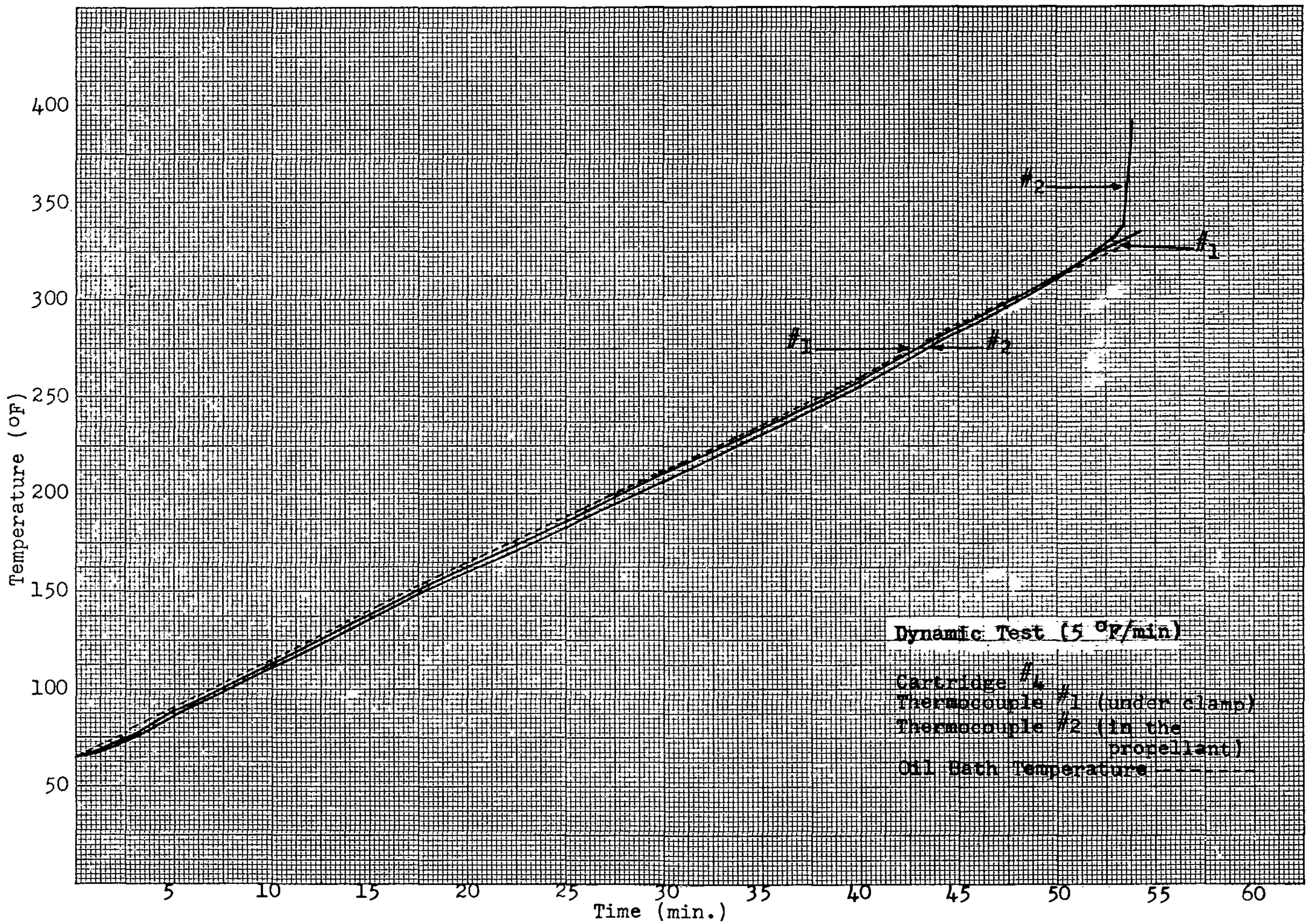


Figure 14

Temperature-Time Curve Controlled By 5°F/min Rate-of-Rise Cam

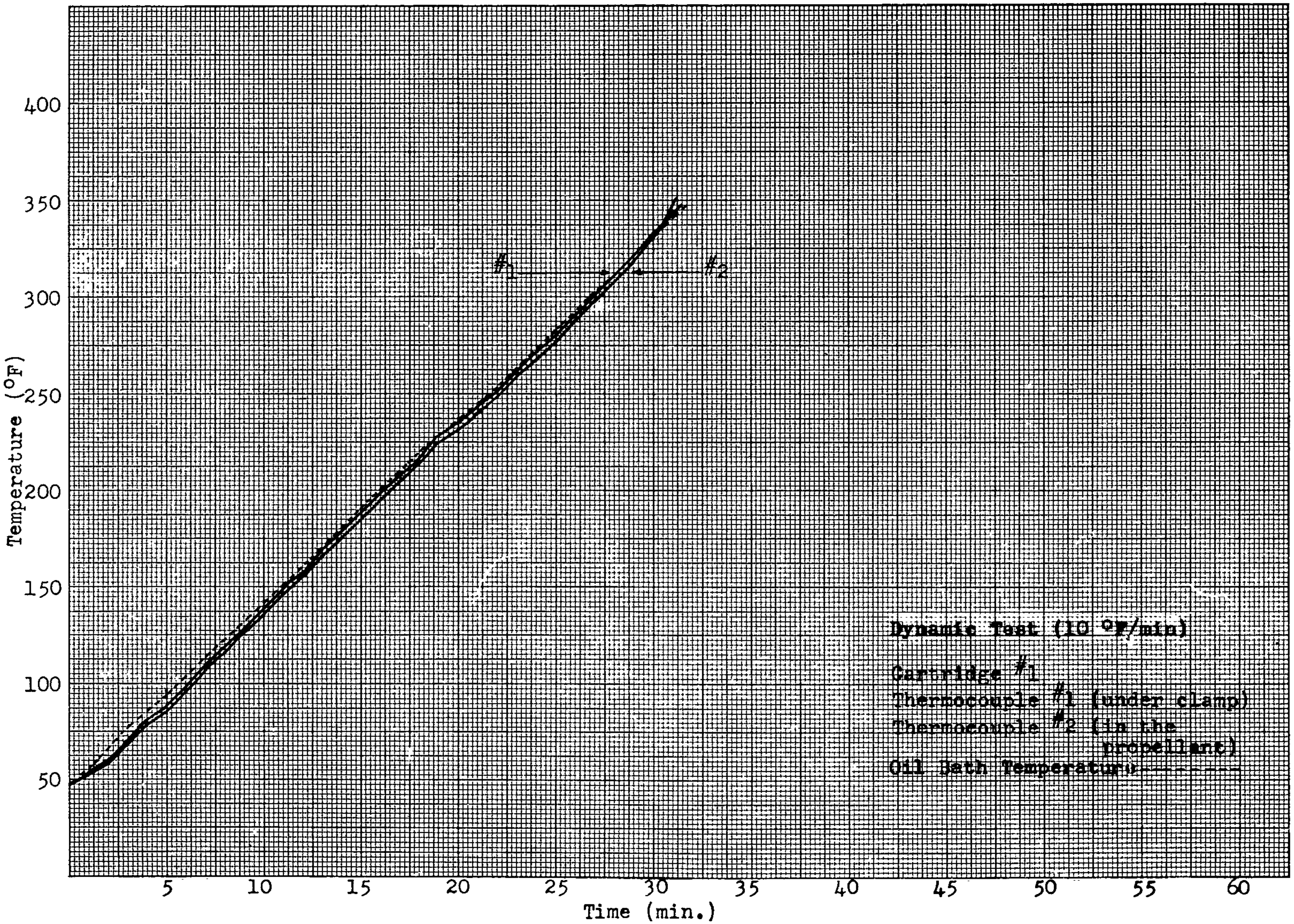


Figure 15

Temperature-Time Curve Controlled By 10°F/min Rate-of-Rise Cam

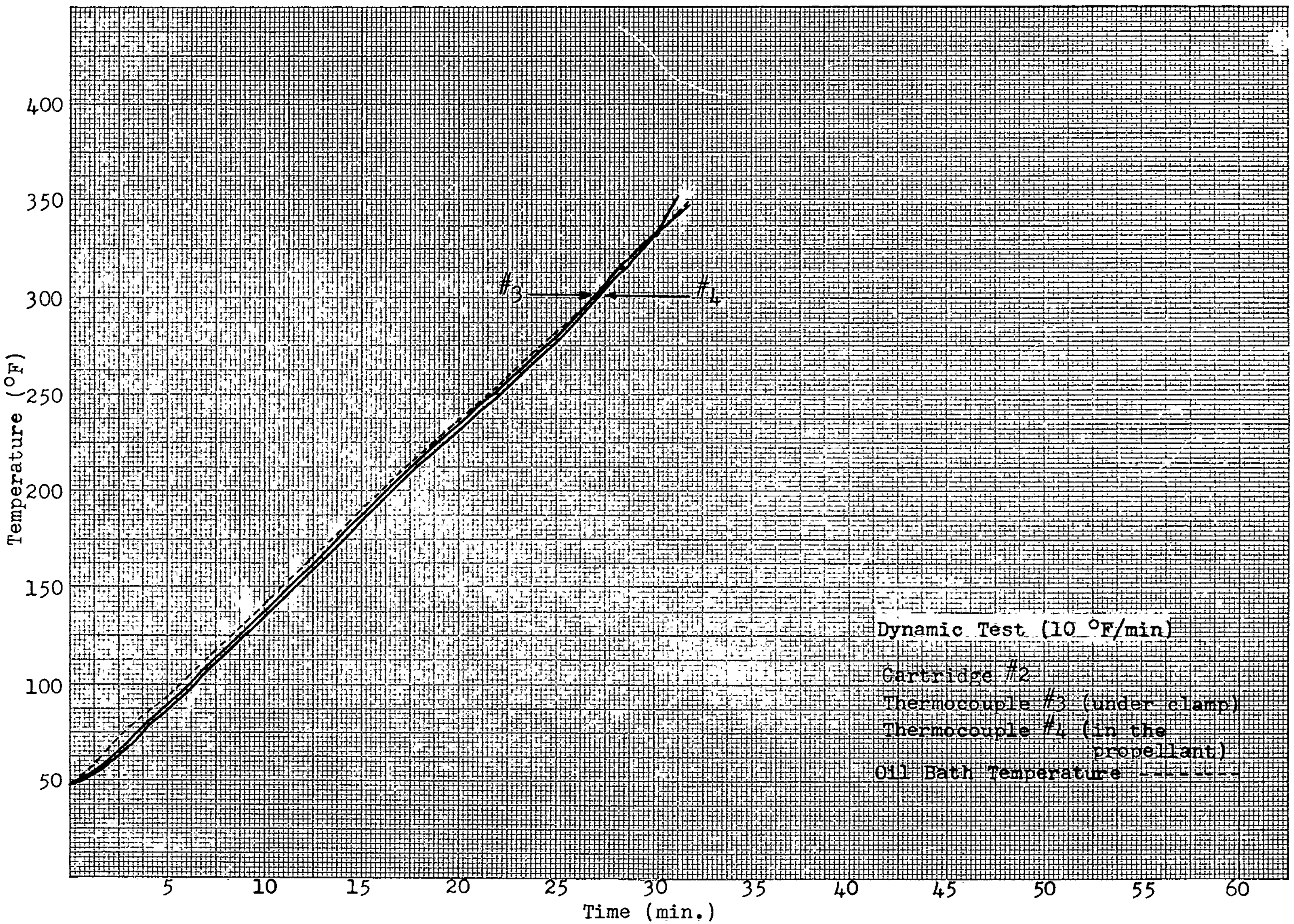


Figure 16

Temperature-Time Curve Controlled By 10° F/min Rate-of-Rise Cam

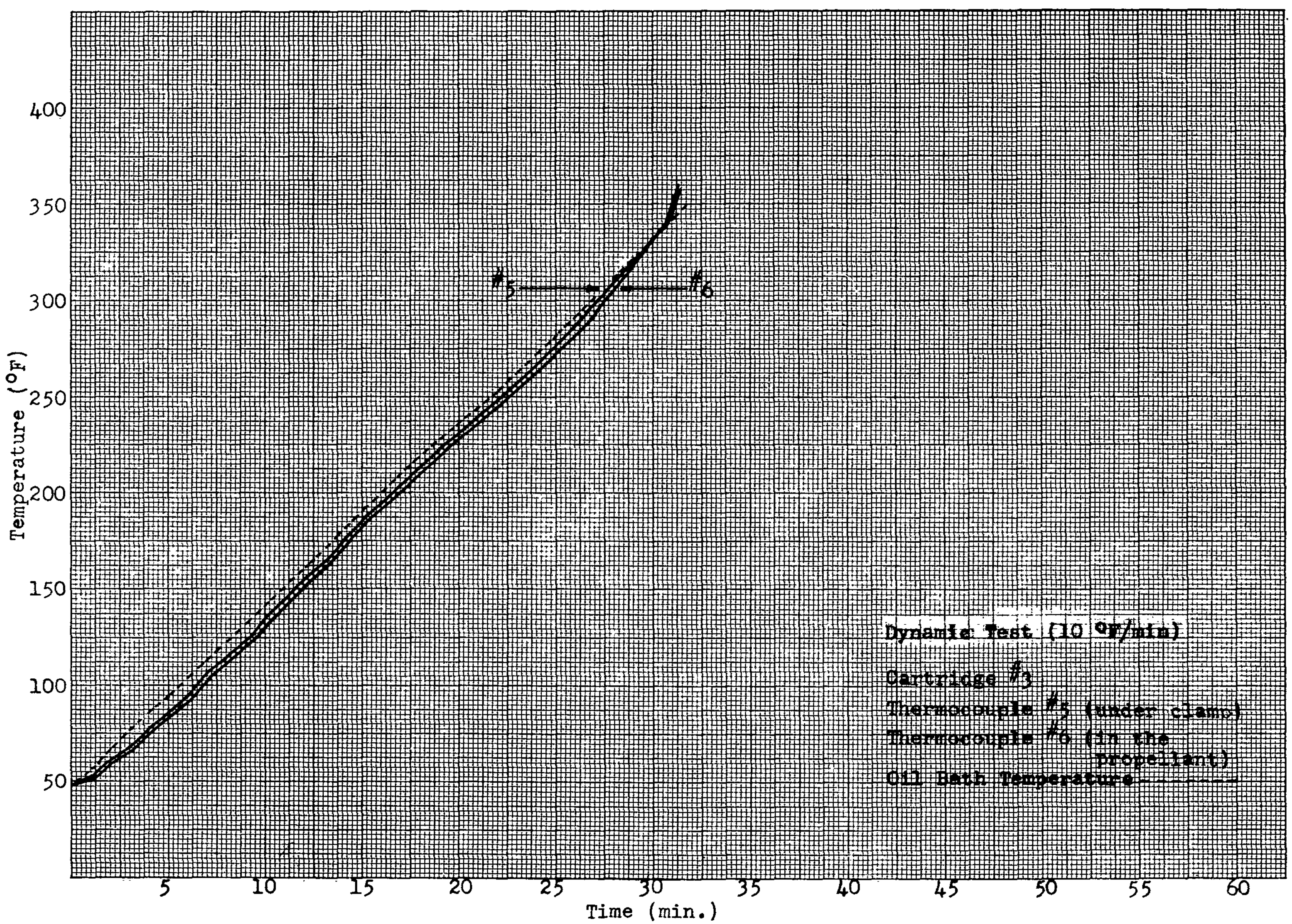


Figure 17

Temperature-Time Curve Controlled By 10°F/min Rate-of-Rise Cam

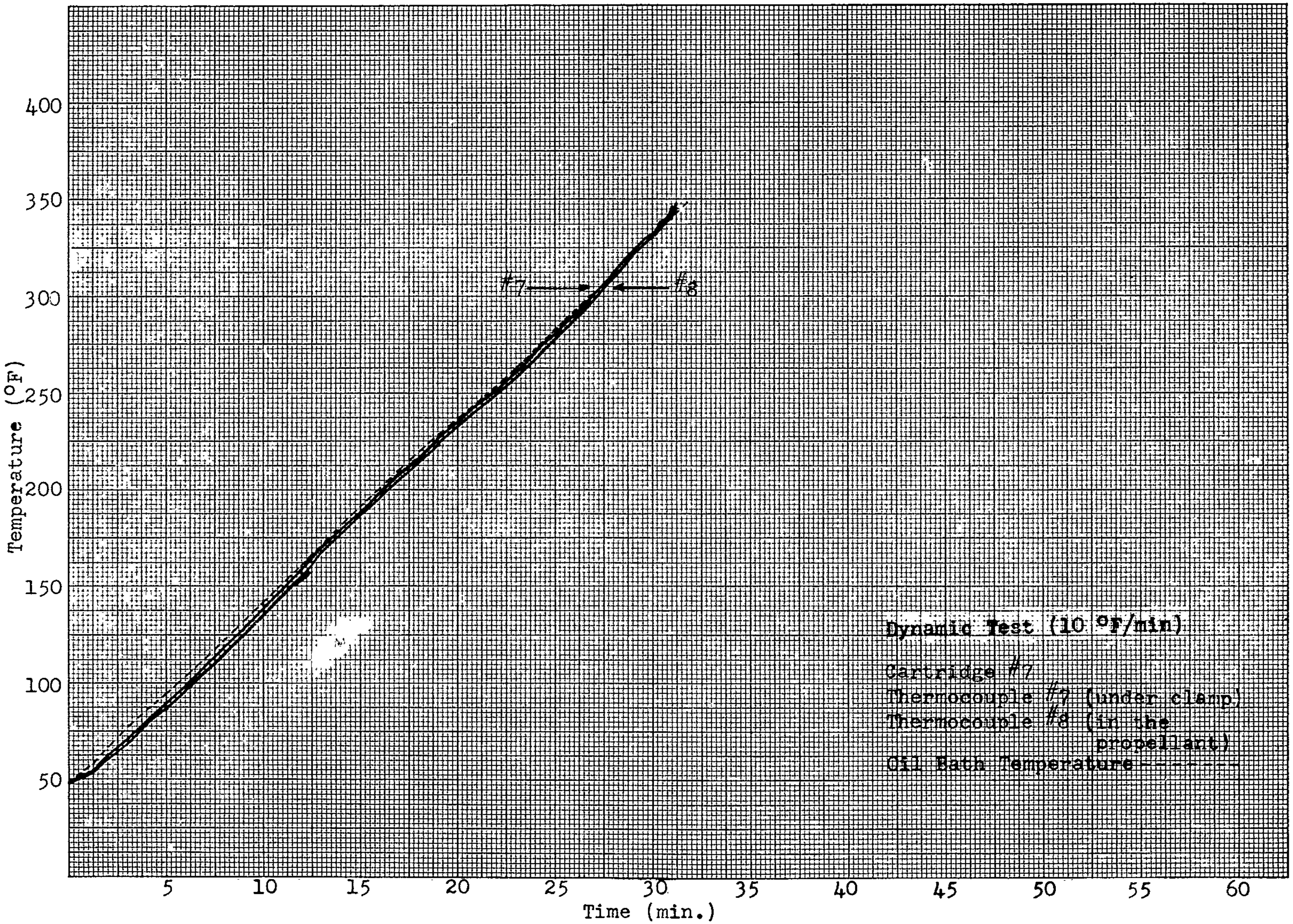


Figure 18

Temperature-Time Curve Controlled By 10°F/min Rate-of-Rise Cam

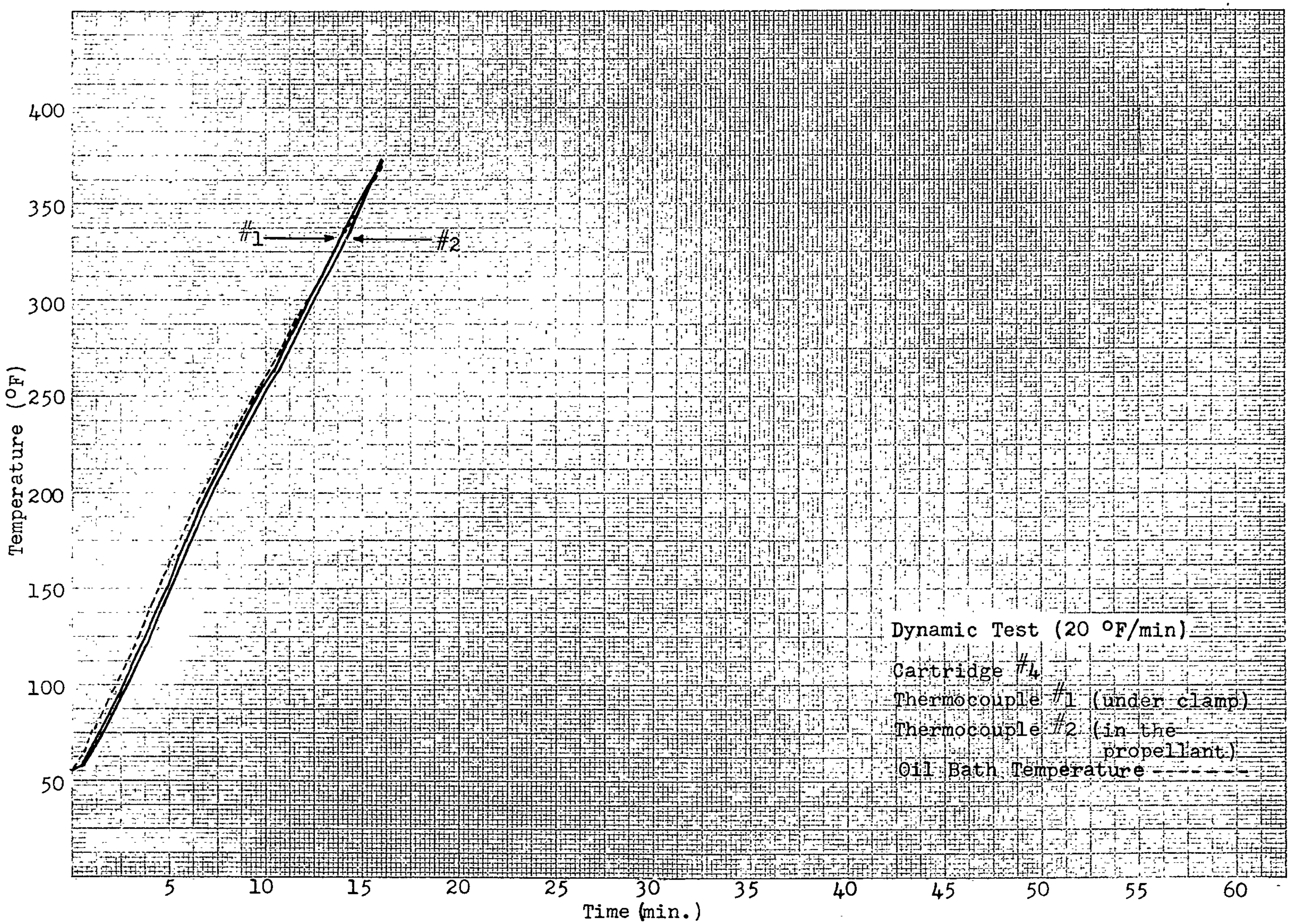


Figure 19

Temperature-Time Curve Controlled By 20°F/min Rate-of-Rise Cam

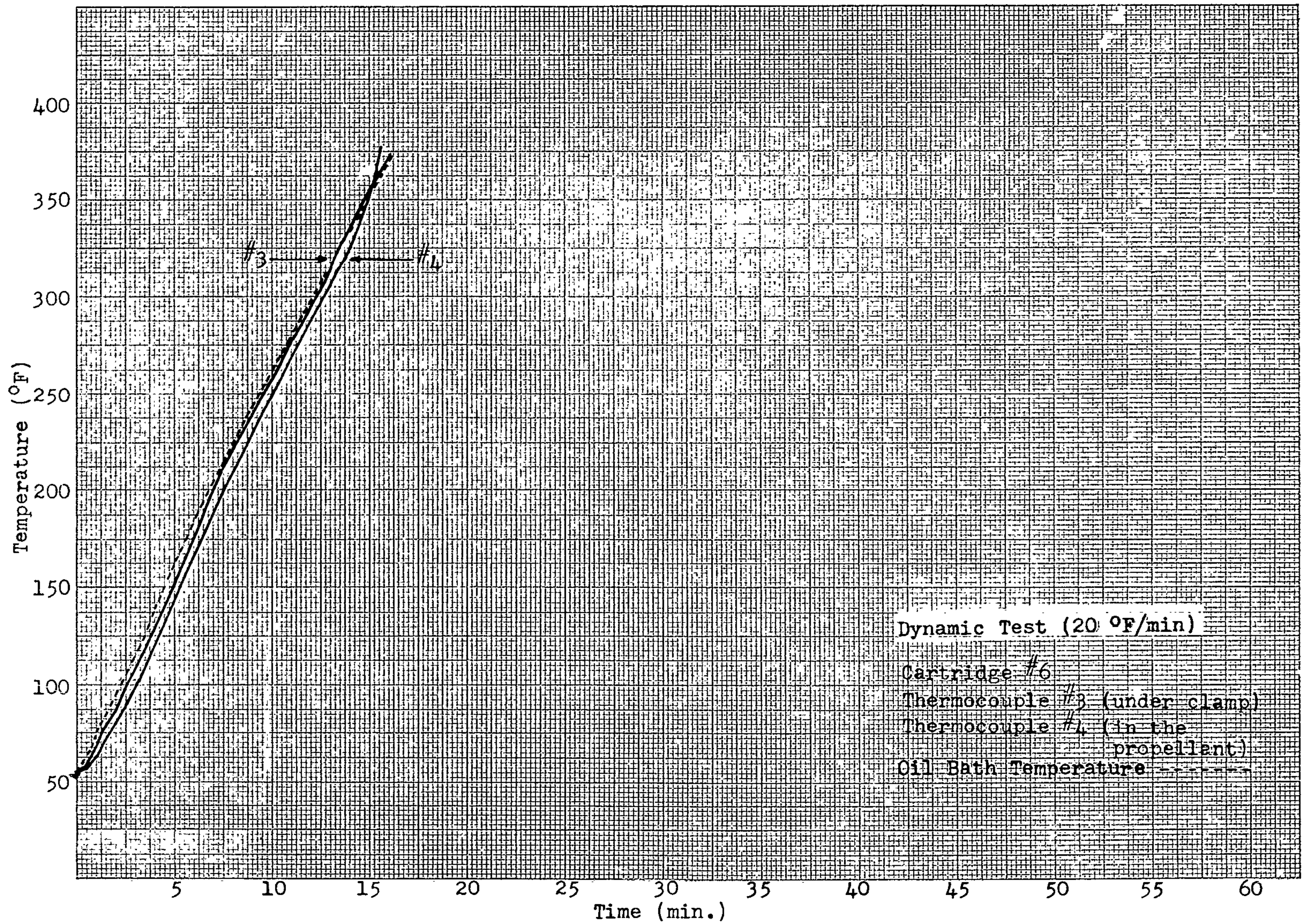


Figure 20

Temperature-Time Curve Controlled By 20°F/min Rate-of-Rise Cam

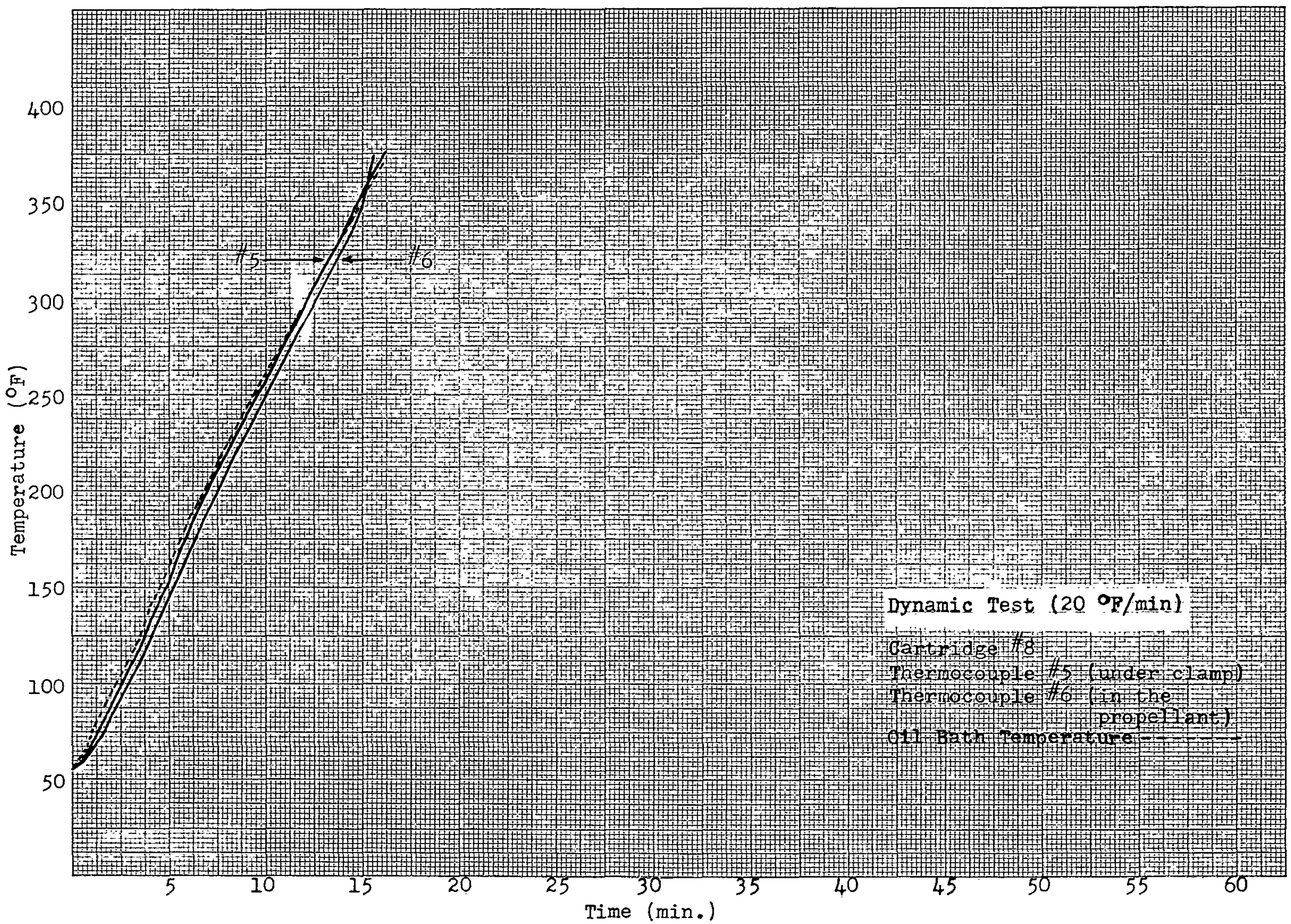


Figure 21

Temperature-Time Curve Controlled By 20°/min Rate-of-Rise Cam

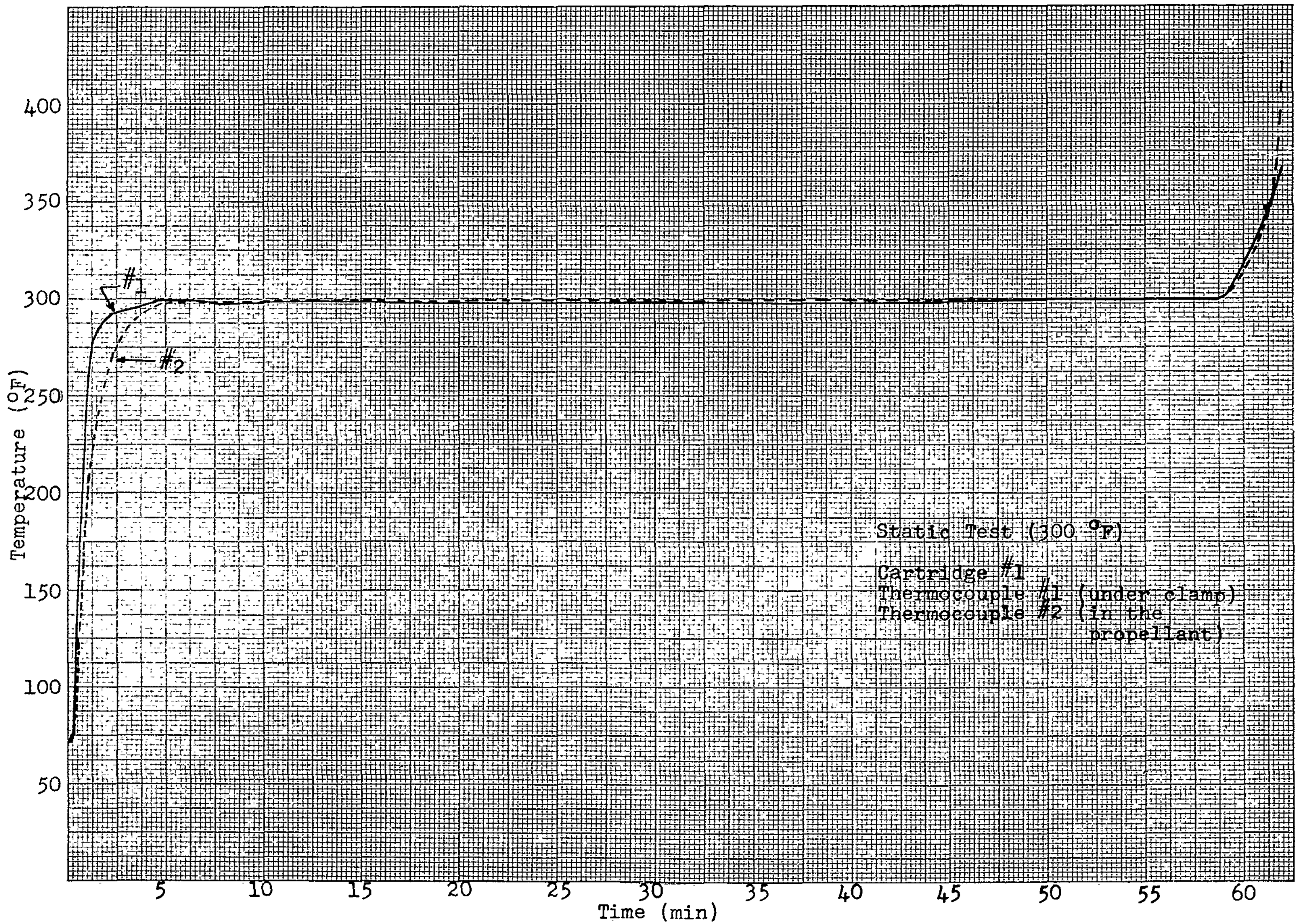


Figure 22

Temperature-Time Curve Constant Temperature Test

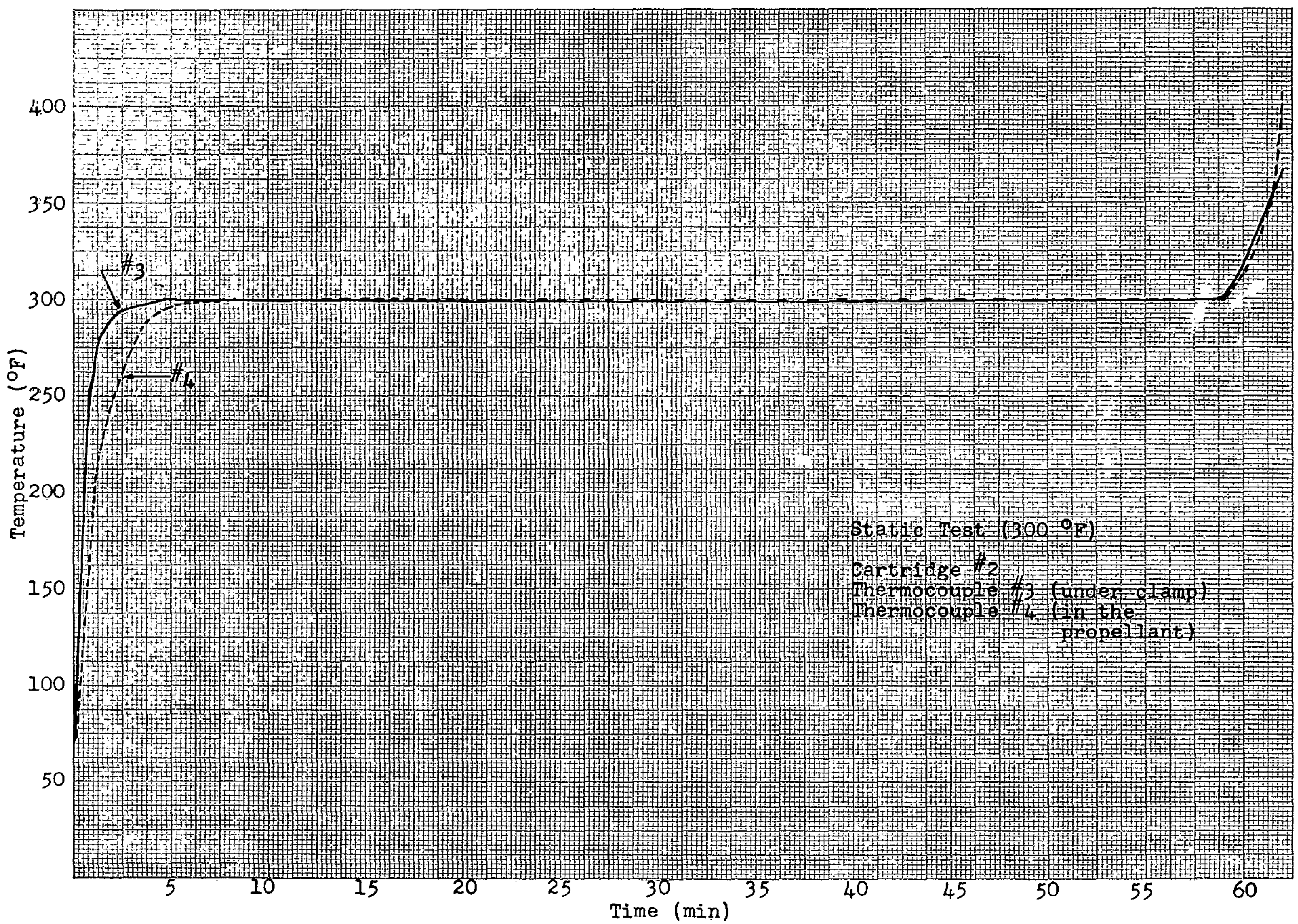


Figure 23

Temperature-Time Curve Constant' Temperature Test

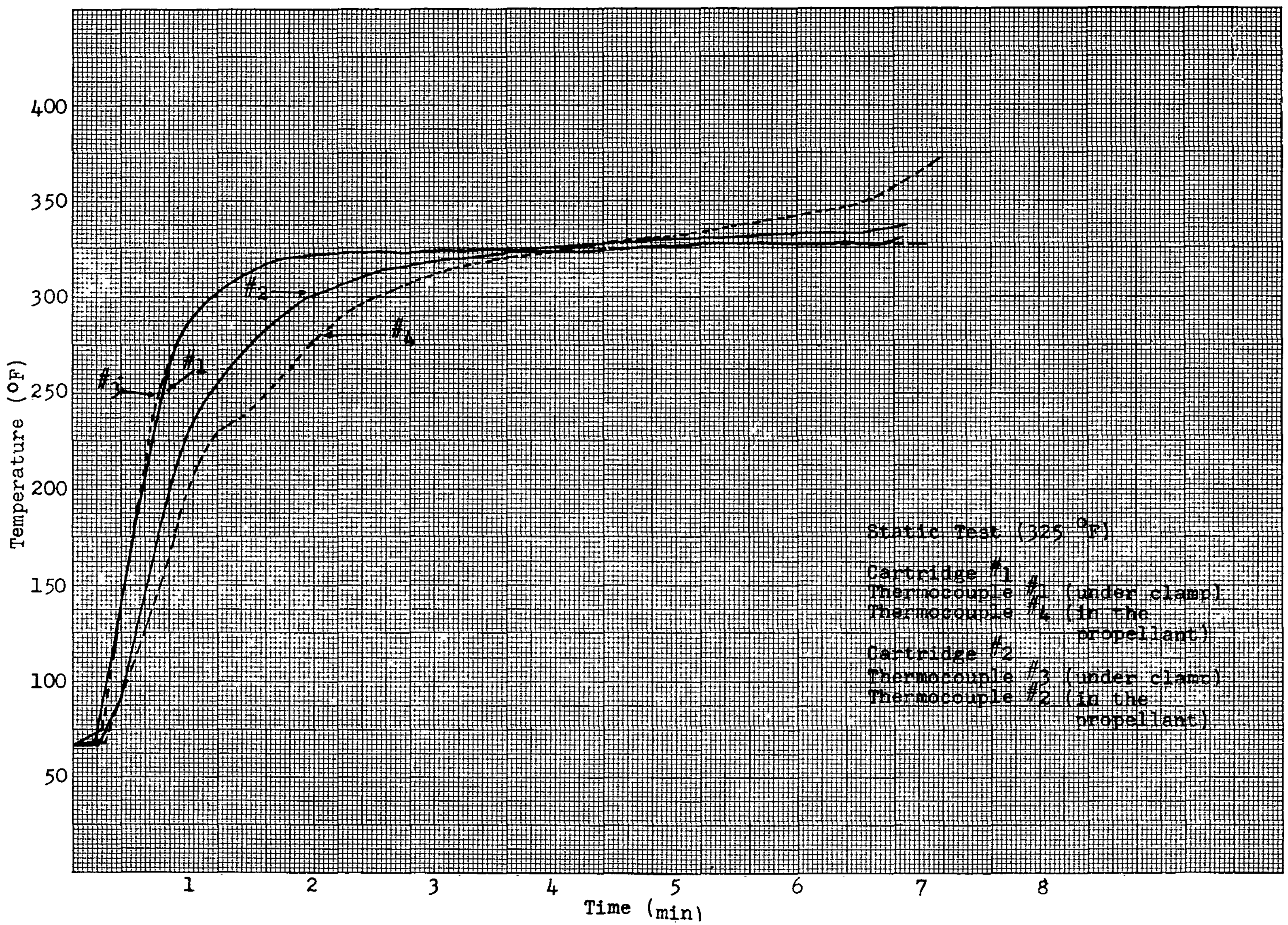


Figure 24

Temperature-Time Curve Constant Temperature Test

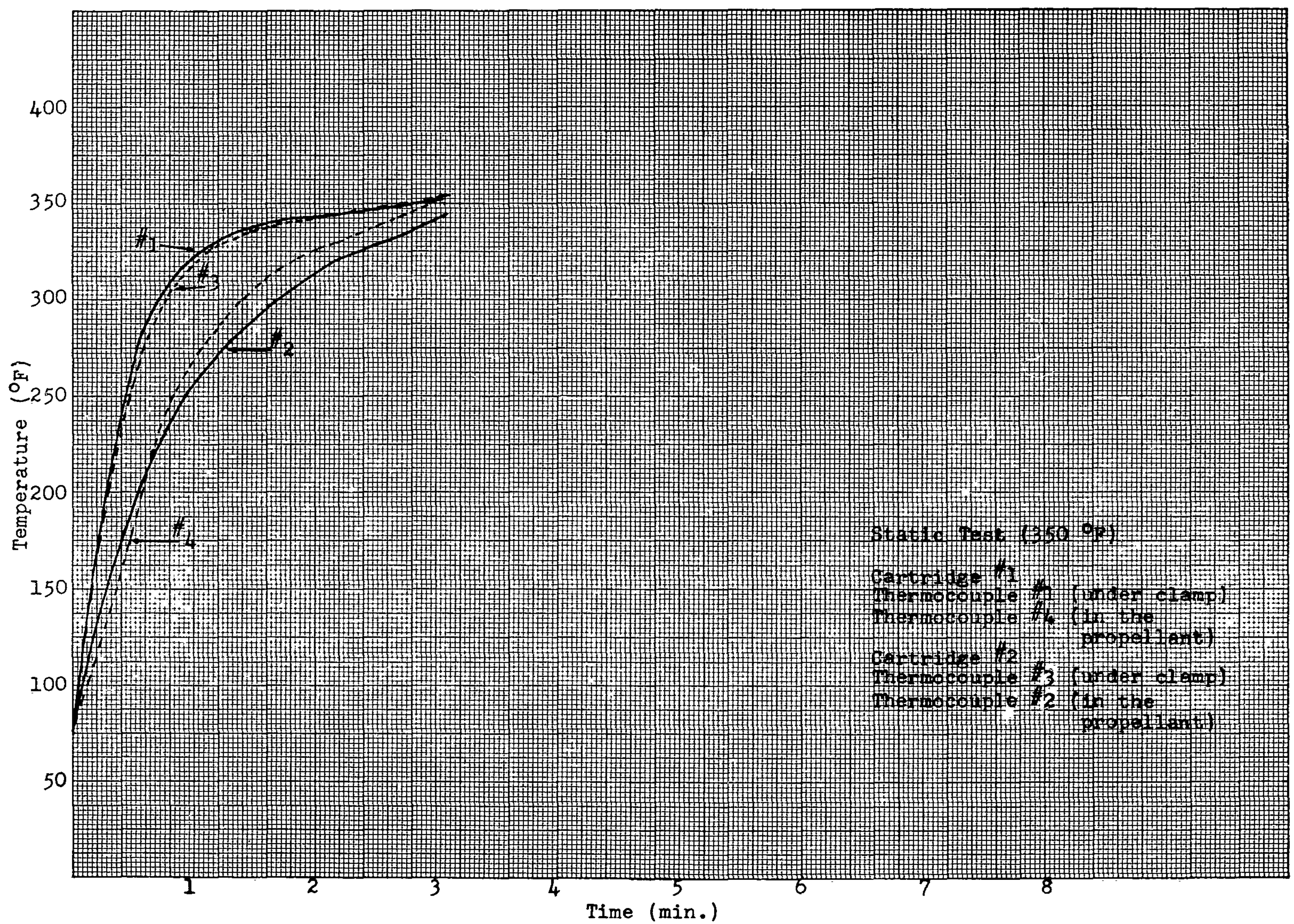


Figure 25

Temperature-Time Curve Constant Temperature Test

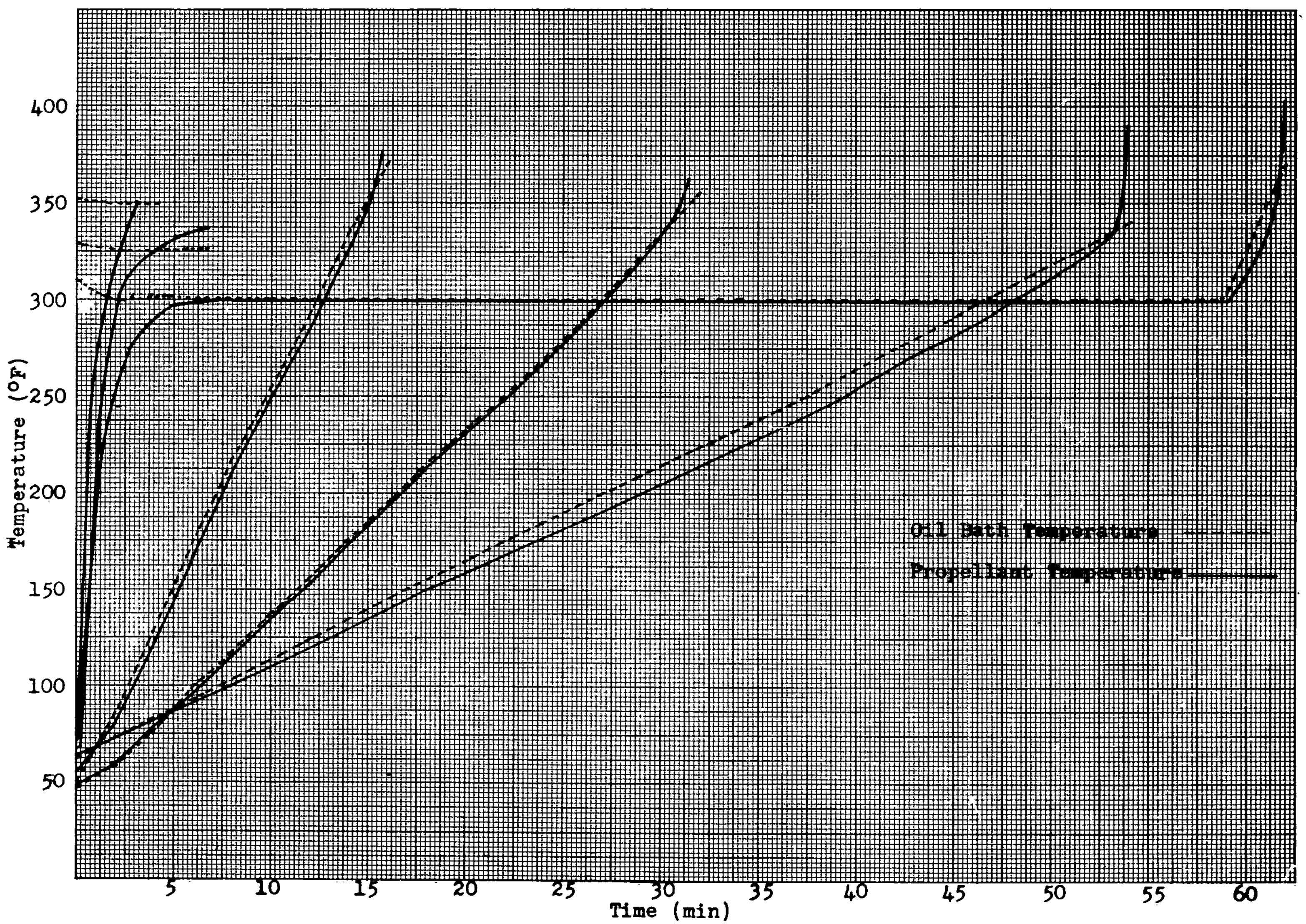


Figure 26

Temperature-Time Curve Summary of Dynamic and Static Tests

APPENDIX B

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SUBJECT ANALYSIS OF REPORT

DESCRIPTOR	CODE	DESCRIPTOR	CODE	DESCRIPTOR	CODE
Test set	TESR				
Cook-off	COOK				
Temperature(tests)	TEMPT				
Cartridges (test)	CARTT				
Power	POWR				
Actuated	ACTA				
Devices	DEVI				
Mark	MARK				
13 mod0)	13MO				

Naval Weapons Laboratory, Dahlgren, Va.
(NWL Report No. 1858)
A test set for determining the cook-off temperatures of power cartridges, by J. Miller and S. T. Fox. 28 May 1963. 9 p. 26 figs.
UNCLASSIFIED

A power cartridge cook-off test set is described, tests conducted to check out the test set are summarized, and a procedure for obtaining power cartridge cook-off data is outlined.

1. Cartridges - Cook-off temperature
2. Cartridge actuated devices
3. Power cartridges
4. Test sets

I. Miller, J.
II. Fox, S. T.

Task: RMMO-33-020/210-1/ F008-11-001

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